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United States Department of Agriculture,  
Agricultural Research Service,  
Soil & Water Conservation Research Division.

Hebrew University Jeursalem,  
Faculty of Agriculture, Rehovot,  
The Department of Irrigation.

Project No. A10-SWC-11

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RESEARCH FINAL REPORT  
P. L. 480

Project Title: FURTHER STUDIES ON THE BLANEY & CRIDDLE FORMULA U=KF  
TO ASCERTAIN THE CONSUMPTIVE USE OF WATER BY PLANTS  
BY MEANS OF ANALYSIS OF CLIMATOLOGICAL DATA.

November 1961 - November 1967

b y

S. Dan Goldberg, Principal Investigator and Head of Department  
B. Gornat, Principal Assistant and Senior Departmental Assistant

Rehovot, November 1967

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SUMMARY

VOLUME I. THE REHOVOT EQUATION

VOLUME II. GENERAL INFORMATION AND DATA

VOLUME III. LITERATURE REVIEW AND BIBLIOGRAPHY



## S U M M A R Y\*

Of the various Climatological Equations to determine the Consumptive Use of crops, none has achieved a greater popularity than the Blaney and Criddle formula. This popularity may be greatly attributed to the simple form in which this formula has been presented and the simple procedure in the determination of the Consumptive Use. However, it seemed to us, that its simplicity is its drawback. Computations carried out in this country, in Iran (in the Quasvin area), in Colombia and in other parts of the world, point clearly to the fact that if this equation presents "reasonable" deviations from actual measurements on a seasonal basis, it gives most unreasonable estimates on a shorter range of time. Indeed Israel is situated climatically in a location where the Blaney & Criddle formula should have given by far better results.

In the search for a formula that would embrace in it additional climatic variables such as: The average Temperature, the true sunshine hours (on a daily basis), the movement of the wind (wind replaces moist air by drier one) and the relative humidity (the indicator of moisture availability in the air), climatic variables that no doubt have a bearing on the Consumptive Use of crops, we decided to carry out this research.

The general procedure of the experiments has been based on the following:

- 1) Selected growers of high agricultural repute, were selected to participate in the research. The common denominator of these growers was the common urge (which dominates Israeli Agriculture) to attain high efficiency of irrigation and use water to its optimal use. The high standard of cultivation was achieved by the proper selection of the growers.
- 2) To carry out the observations in selected, commercially sized, agricultural plots within commercial agricultural areas. Two reasons governed this decision: a) to avoid "Oasis" results of isolated agricultural units, b) to be sure that common (though superb) agricultural treatment would be rendered to the observed plots. In fact, the observed plots had the same treatment

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\*) Presented on request in a non-technical language.



as the remainder of the field. These important considerations have been offset in part by the difficulties in carrying out precise observation under crude commercial conditions. Great vigilance and a high degree of cooperation was needed and attained in these experiments. 3) The drier areas of the country have been selected where water consumption is rather high and where water deficiency is considered to be a major factor. 4) Studies have been carried out in three directions: a) The moisture regime in the observed fields. Moisture fluctuations and determinations were measured by both, gravimetric and by a Neutron Scattering devices (the former requiring a very labourious procedure) to determine and compute the net moisture requirement of the crops. The normal irrigational procedure is that irrigation is carried out at predetermined (normally accepted) schedules, the size of the irrigation is given in accordance with computations. A check is being carried out after each irrigation to verify the duty delivered. Measured over-irrigations are readjusted accordingly. b) Close to the observation plot an Agro-Meteorological station has been erected. The location and the contents of these stations has been carried out in accordance with the accepted specifications and the guidance of the Meteorological Service. Each station is capable of measuring all the desired climatic variables. c) Standard observations over the crop growth were carried out, yields were measured. Observations within plots were carried out in replications in accordance with statistical necessities. The soil property factors were included in the moisture determinations procedures.

The recordings of these observations during several seasons have been screened for authenticity and consequence, a certain amount of material had, unfortunately, to be eliminated, the remainder has been assembled and presented in this report.

Various plottings of the results and particularly the following two types of curves: 1. The Consumptive Use of a crop vs. various climatic factors. and 2. The Consumptive Use of one Crop vs. the Consumptive Use of each of the other crops gave rise to a form of equation which bears the following general form:

$$Et = KM \cdot f(a_1 T, a_2 H, a_3 W, a_4 S)$$

*and so on*

*what is? clim factors (see pg. 36)*



where E<sub>t</sub> is the average daily evapotranspiration. T is the temperature in Centigrade. H is the average Relative Humidity in percent. W is the daily wind distance in K'm per day and S is the average daily hours of sunshine.

Computations were carried out to calculate multiple regressions and six evapotranspiration equations were presented, titled the REHOVOT FORMULAE.

Climatic conditions in Israel point to the fact that the Temperature, Radiation (or sunshine) and the Crop factors are significant, however, lack of significance and insignificance in the Humidity and the Wind variables respectively, have been noted. The reasons of lack of significance in the last two factors is attributed to the small variations in humidity and wind in the locations where our experiments have been taken, indeed in most of Israeli agricultural areas. This does not mean, by no means, that these factors are insignificant in windy highlands of dry climate such as Quasvin in Iran or similar global areas of similar climatic conditions.

Various computations of evapotranspiration values computed from Blaney & Criddle, Thornthwaite and the Rehovot Formula vs. measured evapotranspiration have been presented in tables which give rise to a promising use of the Rehovot Formula.

To signify the findings of this research, we may summarize it as follows:

1. The research had its aims to present an Evapotranspiration formula and this has been presented.

2. It was suggested and carried out that the formula (The Rehovot Formula) would be based on findings derived from commercially operated fields, and this has been achieved.

3. Reliable and selected data has been presented in this report used in the derivation of the Rehovot Formula and could be used by others to follow.

4. Other supporting materials, comparative values relative to other climatic Formulae and a considerable Review of Literature is presented.

5. Five Publications of direct applicatory use have been published, procedures of irrigation in the respective areas of experimentation have ensued in practice.



VOLUME I. THE REHOVOT EQUATION

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## INTRODUCTION

The effects of climatological variations on the consumption of water by plants is a well established phenomenon; indeed, a very wide range of research has substantiated that various parameters of the Astro-Meteorological factors and the agro-climatrical variables have great influence on the water consumption of plants. It should be born in mind that the plants themselves, through their physiological habits and their normal growth, and the soil and water properties in which and under which these plants dwell, have certain effects on their demand for water. Today we tend to believe that even the method in which water is being applied to plants has a direct bearing on their water use, and this, without bringing into account water application efficiency practices. However, climatic variables have the greatest influence on the water use of cultivated crops. Though the Consumptive Use of a crop is defined as the total amount of moisture to be replenished to the soil to bring a crop to complete maturity, this term contains avoidable and unavoidable losses which the plants under normal cultivation enjoy no benefit from. We therefore prefer to segregate certain "losses" or water use by the plant, which governs its existence and which cannot be avoided, as the "Evapo-Transpiration" rate or sum per season. This is defined as the amount of moisture depleted from the ground by the plants which is transpired through its leaves and evaporated from the ground. Theoretically the Evapo-Transpiration could almost be considered as the only unavoidable moisture loss from the ground and could be termed as the net use by the plant.

Though many a scientist tried to give formulae and methods to establish the Evapo-Transpiration of plants under varied climatic conditions, three schools of thought are the better known: 1) Penman's Approach (Penman 1948) which fundamentally bases its calculations on the equations of Heat Balance and Diffusion; thereby getting the Potential Evaporation (this involves in addition to measurements of radiation, the measurements of air temperature, humidity,



velocity of wind and hours of bright sunlight). To obtain the Evapo-Transpiration, the Penman method utilizes certain empirical conversion indices which should convert the theoretical potential evaporation to an estimated Evapo-Transpiration of a crop. This method has gained great popularity among scientists, particularly due to the fact that it involves a very sound scientific basis. The greatest disadvantage of this method is that it involves laborious computations which put a burden on agricultural practical research, but the greatest disadvantage, and this is the reason why some agricultural scientists have had to look for a different approach, is that it involves taking toll of Radiation measurements requiring special apparatus and skill in taking observations. For practical and common use in agriculture simpler methods are preferred. 2) The Thornthwaite method. It seems that in order to avoid difficult and often unobtainable measurements of vapour flux and heat balance, with all the complicated instrumentation involved under normal agricultural conditions, Thornthwaite suggested an empirical formula for any location on the Globe, at which maximum and minimum temperatures are recorded. It however brings into account  $I =$  a heat index which is a function of the monthly normal temperatures, and  $a$  = an empirically determined exponent which is a complicated function of  $I$ . The arithmetic solution of Thornthwaite's equation becomes very complicated and therefore, through the very fine work by Messrs. W.C. Palmer of the US Weather Bureau and A.V. Havens of Rutgers University, a graphical solution has been devised for this equation (April 1958). It was regretted that in his publication "The accuracy of meteorological estimates of Evapo-Transpiration in Arid Climates" (1961), Dr. G. Starkill came to a very definite conclusion that "Thornthwaite's formula led to considerable underestimates of the amount of evapotranspiration". It was felt that under arid conditions where this formula is greatly needed (most underdeveloped countries are climatically arid), the Thornthwaite approach lacks the necessary accuracy. 3) The Blaney and Criddle formula. In their publication SCS-TP-96 1950, USDA, the authors suggested a very simple formula and procedure to determine consumptive use (in our case evapotranspiration) of crops from climatological data. It was made to work particularly in the Western States of the U.S. Results obtained



for seasonal allotments of water to crops have been satisfactory. This very useful information has numerous applications; for one, it puts the farm crops and the water supply (with all its hydraulic and mechanical facilities) on a common balance sheet. Of the important factors one can mention: What is the peak demand of a particular crop or set of crops? Can the irrigation system (pipes, sprinklers, canal maximum flows, etc.) stand up to this demand? For a given water supply, what extent of crop cultivation, both in acreage and period of seeding, can be successfully ventured? What is the basis of the design of the irrigation layout, storage, pumping, pipe and canal layout, type of application, etc.?

It seemed to us that in their simple empirical equation, Messrs. Blaney & Criddle base their solution for estimating the evapotranspiration on mean temperatures and astro-geographical daylight hours, where many more simple agro-meteorological factors could easily be brought into the formula (or into procedure of solution) to give a better and closer estimate for shorter and better suited critical periods of water use. Our study makes as accurate as possible measurements of moisture deficiencies in commercially grown crops with very accurate agro-meteorological observations derived from STANDARD agro-meteorological stations situated at close proximity to our agricultural fields. The following illustration will summarize the aim of our research: assuming that we have reached through this research an improved formula or a better procedure to ascertain the moisture requirement of crops, and let us assume that in one of the less developed countries, say, India, Persia or Central Africa, there are known results of an agro-meteorological station (or even some of the climatic data), it is our aim to estimate and foresee the extent of development of agriculture from a certain water supply, to lay foundations on the consumptive use, particularly in the critical period, and to provide design data as to the water demand that otherwise should be gotten through lengthy experimental repetitions where there is no past reliable experience.



It is a fact that the impetus to undertake a research on "Further studies of the Blaney & Criddle formula" has come from lack of reliable data for design of irrigation projects and irrigation engineering standards for better irrigation practices. This country is an example of the immense need to conserve water, to make sure that water is being used to its optimal rate and to check that none is being wasted. Winter floods and treated sewage are being directed and stored underground; city dwellers and industrial plants are rationed on their water consumption. No wonder therefore that the bulk of available water resources, from all sources, are intended for agricultural use. Having gone through an extensive study of our Hydro-Geological potential, our surface water resources, the return water from irrigation, sewage or any other conceivable source, we now see the final sum of how much water (on a yearly basis) there is to be used. By the year 1970 we hope that all this water will be put under control, either directly available for use, or stored underground for further use, and with the exception of new economical technological advances in the field of sea water desalting, we have nothing further to offer. It is therefore very important, and indeed the greatest task that faces us now in this field, to know, understand and properly apply water, soil and plant relationships to get optimal agricultural crops with the least amount of water.

In their formula  $U = KF$ , where  $U$  is the use of water in inches,  $K$  an empirical coefficient related to a certain crop (designates crop characteristics),  $F$  a sum of the monthly factors ( $f$ ) for the season (sum of the products of mean monthly temperature ( $t$ ) in Farenheit and monthly ( $p$ ) percent of annual daytime hours). For shorter periods, Blaney & Criddle suggest  $u = kf$  which is the consumptive use in inches. For our conditions in this country as described above, and indeed in many parts of the arid undeveloped portions of the globe, we need a formula or at least a method, to determine short period consumptive use of plants. It seems that similar experience had been gained by Professor J. E. Christiansen of the Utah State University; in his letter to us dated October 2nd, 1962 he states "I found that the monthly values of  $k$  varied from a minimum of



0.84 to a maximum of 1.91". In a different portion of his letter he states "I have read your original letter with considerable interest because the objective in our research on evaporation and evapotranspiration is almost the same as yours - to develop a usable formula that will give more accurate results than the Blaney-Criddle formula". It only shows that this lack of usable formula requires a solution.

#### EXPERIMENTAL PROCEDURE

The basis of our investigations is that we enter into existing farms (or settlements) mostly in the arid sections of the country. We set up Standard Agro-Meteorological stations (details of which will be given later). We follow up practically the complete growth of all its crops (vegetable, industrial and fruit crops) with its past and present treatments, each crop with its specific recognized variables. Irrigation delivered (moisture added) by computing moisture deficiencies within the root zone, by sampling soil samples before and after irrigations, we have placed the emphasis on two distinct phases of research:

1. Crops have to be grown commercially (for many reasons). By growing crops commercially we do not mean that we enter a random farm with doubtful experience and check moisture deficiencies. What we do is to enter farms of considerable growing potential, high yields and superior practices, with a considerable degree of agricultural intelligence, that would grow for themselves commercially under the best practices through our complete moisture control. Farms are being selected in the arid portion of the country where water prices and water use practices are of great importance to them. The better and more efficient use of water is our joint interest.
2. We carry out agro-meteorological data concurrently and record through a standard, internationally recognized practice, the normally recorded data. We believe in the concurrence of the observations to aid in a closer analytical processing of data relative to moisture demand and deficiencies of the crops grown. When we had to make the decision as to what climatological records are to be taken, we were faced with three



alternatives: a) to make the minimum number of variables, such as the temperatures only, or temperatures and a single additional variable; in this case we would have come back to some form of the Blaney Criddle formula with its limitations on its accuracy when computed for short period intervals. b) to indulge in rare and complicated instrumentations, of cosmic and radiation studies of the Penman vapor flux and energy heat balance, equipment and procedures cumbersome requiring highly skilled technicians seldom available in underdeveloped countries. c) to base the agro-meteorological studies on data normally obtained from standard agro-meteorological stations. The purpose in devising a standard layout for an agro-meteorological station was to lay a foundation for a standardized form of instrumentation and data recording so that it would serve agricultural districts in crop production. Knowing in advance that some important areas of underdeveloped populations might lack some of this standard data taking, we have come to a conclusion that for once there is a standard layout for such a station, and in future such layout and data taking procedures would be the standard agro-meteorological practice. We have therefore decided to base all our climatic observations on this.

The Agro-Meteorological stations have been set in accordance with the internationally accepted layout, and in cooperation with our well advanced Israel Meteorological Service, under their guidance and help with their punching cards and accumulation of data. We are grateful to our meteorological service for their cooperation.

True to our general conceptions we have set two experimental stations in arid sections of the country: 1) in the settlement of SAAD, situated on the western portion of the Arid Negev, close to the city of Gaza. The settlement consists of 190 grown up members, all belonging to a religious group. The total overall income of this community is about 2 million Israeli pounds per year. They possess about 2500 acres of dry farming (with supplemental irrigation), 50 acres of alfalfa, 300 acres of industrial crops, 250 acres of



assorted vegetables, 250 acres of plantations (citrus, and other fruit trees). The crops that have been selected for our observations included: Sugar beets, cotton, alfalfa, grapes, apples and plums. 2) at Nir Itzhak on the South-western fringe of the country in a sandy and desert environment, this remarkable settlement with its superb and intelligent group of settlers has given us one of the most unique situations of an extremely high level of agricultural intelligence, under desert conditions with superb crop results. Our observations here comprise five (5) crops: A lemon orchard, apricots, A vineyard, A field of Alfalfa and Ground-nuts.

Our third station Kefar-Hayarok is an agricultural highschool in possession of 1000 acres of cultivated agricultural land. This establishment has placed at our disposal its entire farm facilities, buildings to house our laboratories and plots for sprinkle irrigation studies, to study consumptive use of: Apples, Peaches, Vineyard and Citrus Orchard.

Procedure in the fields: Close observations follow two main factors: the moisture changes as it appears primarily by soil samplings and the development and changes in the crop growth. For the moisture study we carried out preliminary investigations in each field to include: Moisture percentage at Field Capacity, volume-weight ratio at soil depths of 1 ft intervals (this was done by digging holes in the ground), samples have been brought to our central laboratory and physical and chemical analysis carried out, such as wilting percentage, % of salts,  $\text{CaCO}_3$ , Ph. Four holes and four sets of analysis have been carried out in each field. Further moisture studies have been taken at close proximity of these basic "holes".

As it is well known that the number of sample borings per observation are a function of the uniformity of the soil within the field, and having consulted specialist statisticians on the number of borings to be observed bearing in mind the small variance in soil characteristics, it has been decided to take moisture samples at six (6) locations in each field. Two sets of moisture observations



have been taken - one, a day prior to the irrigation, through which the study of the following irrigation has been computed and applied, and a second, 48 hours after application to ascertain and confirm the justifiable irrigation. Samples are taken at foot interval (subject to the depth of the root zone), weighed in our field laboratories before and after oven drying. It could be noted that this was a highly labourious task requiring diligence and patience.

Two other independent methods verified the moisture-soil sampling results; one, water meters at the head of each plot and two, since all our fields (at least in Saad) and now in Nir Itshak and in Kefar Hayarok are sprinkle irrigated, the capacity of a sprinkler, a sprinkling line, spacing and pressure gave a proper counter check.

Moisture study laboratory: The distance between our experimental sites and the Faculty Laboratory in Rehovot is considerable, we found it imperative, to have on each experimental site an individual local laboratory to determine soil moisture deficiencies. The laboratory consists of the following essential instruments: 1. Metler K automatic weighing scale, capable of measuring net soil weights. 1. electric soil oven ( $110^{\circ}\text{C}$ ), complete set of boring equipment. Field wooden cases containing 24 pre-weighed aluminium soil containers and other smaller instruments; The study of the soil structure and texture, which is performed at great intervals, these are performed in our Rehovot Base laboratory.

Although we have a Neutron device, we decided not to relax our gravimetric readings, and we duplicated each gravimetric by a Neutron study. We relaxed our gravimetric procedure only after two years when we were sure that with the Neutron we achieve at least as good results.

The observations over the crop growth have included the following: All the treatment of the soil, fertilization, vegetative developments and changes of the crops; in sugar beets the height of the plants, the ratio between the leaf area and the soil area, or L.A.I. probe, rootlets per unit area and



percentage of sugar. In alfalfa we observed the height of plants, height before cutting, average crop per cutting, interval between cuttings, and dry weight. In cotton we observed the average height of the plants, number of plants per unit length, distance between rows, approximate date of bloom, number of cotton balls per unit length, date of bursting of cotton ball. These indications have a direct bearing on the consumptive use of the respective plants. Similar typical observations were made on vegetables, fruit trees and other crops.

Procedure in our Agro-Meteorological Stations: In close proximity to each and every experimental area we erected, under the auspices and with the guidance of our Meteorological service, a Standard Agro-Meteorological Station. Each station consists of the following instruments: 1 Stevenson screen complete; 1 Dry Thermometer bulb placed in the screen; 1 Wet Bulb Thermometer with a cotton wick placed in the screen; 1 Maximum Thermometer placed in the screen; 2 Minimum Thermometers placed 1 inside the screen and 1 (a grass type) on the ground (outside the screen); 1 Thermograph placed in the screen; 1 Hygrograph placed in the screen; 1 Piche Evaporimeter placed in the screen; 1 Standard or recording rain gauge placed in the yard; 1 Standard Class "A" Pan properly erected in the yard; 1 Anemometer mounted on a 3.5 m pole; 1 Wind Vane placed close to the anemometer; 4 thermometers to record temperatures at various depth of the soil; 1 Sunshine recorder based on a glass ball lens and paper strips capable of being burned; special radiation recording instruments are held by the Meteorological Service at several locations in the country, the recording of which are readily available to us.

All the instruments are checked and recorded three times daily, at 08.00, at 14.00 and at 20.00 daily. Field recording books and summation sheets are available daily and at the end of each month as required.

The method of irrigation: All our fields are sprinkler irrigated. Practically all the fields are night irrigated with low intensity irrigation of



about 6 mm per hour (the infiltration rate is two to three times as much). Irrigation by night avoids losses due to direct radiation and avoids harmful wind distortions. The sprinkler pattern efficiency exceeds 90% by the Christiansen standard. Scheduling of irrigation times is pre-determined according to the best practices of each location, however, the amount of duty of water delivered at each irrigation, this is being computed carefully and checked by taking samples after irrigation (48 hours after application) to ascertain that no water is lost below the rooting zone. If water is lost below the rooting zone, this is being deducted from the effective water duty that has been applied. We do believe that under these conditions, and only under such conditions we could have a thorough control over our irrigation applications.

#### RESULTS AND ANALYSIS

The first step was to eliminate those data which were unsuitable for statistical analysis. These included figures for which the climate was not the dominating factor in affecting consumptive water use. Examples of discarded data were those obtained during periods of predetermined drought during the early spring when the plants had still not developed their leaves, and in cases where there was reason to believe that drainage water was included in the evapotranspiration figures.

Upon completion of eliminating unsuitable data, it was clear that although thousands of soil moisture determinations have been made, the number of reliable measurements of consumptive water use for a particular crop was not great. It was even necessary to exclude from the analysis crops for which the amount of data did not appear sufficient for making the statistical calculations. The data for the balance of the crops are presented in the accompanying tables. Each crop appears in a separate table, representing the results for each year of the study. See tables 1 - 15.



Table 1

- 11 -

Location: Saad

Crop: Apples

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	14.5.63	23.5.63	9	3,9	49,9	11,8	194	21,7	8,6
2	25.6.63	11.7.63	16	5,1	62,3	11,5	181	25,0	8,0
3	18.7.63	26.7.63	8	5,1	60,7	11,4	180	26,5	8,2
4	8.8.63	21.8.63	13	5,3	62,2	11,3	161	27,1	8,0
5	27.8.63	5.9.63	9	3,1	52,9	8,1	141	26,2	8,5
6	5.9.63	25.9.63	20	3,4	57,6	10,5	162	25,3	7,4
7	1.10.63	16.10.63	15	4,0	63,3	9,6	146	25,0	6,0
8	16.10.63	31.10.63	15	3,8	56,5	6,5	169	21,8	5,7
9	13.11.63	20.11.63	7	2,3	63,4	9,3	124	18,1	3,2
10	1.7.64	8.7.64	7	5,4	63,1	12,0	136	20,1	7,2
11	8.7.64	13.7.64	5	5,5	64,4	12,3	140	24,0	8,8
12	20.7.64	27.7.69	7	4,8	69,5	12,2	120	25,8	7,8
13	27.7.64	3.8.64	7	4,0	69,3	11,7	127	25,3	9,5
14	12.8.64	18.8.64	6	4,5	63,5	14,0	126	20,4	5,5
15	6.10.64	12.10.64	6	4,5	64,5	10,0	122	17,7	4,2
16	1.10.64	6.10.64	5	5,4	60,7	10,2	159	21,1	3,2
17	12.10.64	22.10.64	10	4,3	73,9	8,9	99	21,8	3,7
18	5.4.65	14.4.65	9	2,1	60,9	8,4	135	16,0	4,6
19	10.5.65	17.5.65	7	3,7	65,1	12,6	139	18,5	6,6
20	17.5.65	27.5.65	10	4,5	57,6	12,1	152	20,6	8,3
21	27.5.65	1.6.65	5	4,7	53,9	12,1	155	23,9	9,3
22	9.6.65	21.6.65	12	5,1	50,7	12,5	147	24,8	8,5
23	29.6.65	13.7.65	14	6,0	66,7	12,4	161	24,7	7,9
24	20.7.65	27.7.65	7	4,4	61,8	12,3	155	24,9	9,6
25	27.7.65	1.8.65	5	5,7	60,2	12,6	136	25,1	7,5
26	10.8.65	22.8.65	12	5,6	69,2	11,5	126	25,3	7,0
27	29.8.65	14.9.65	16	4,3	67,9	11,5	122	23,9	6,2
28	14.9.65	21.9.65	7	3,7	69,1	8,6	130	24,3	5,8
29	29.9.65	31.10.65	23	3,2	62,7	8,4	123	20,9	4,6
	31.10.65	15.11.65	15	2,9	67,3	8,4	89	17,7	3,3



Table 2

Location: Saad  
Crop: Plums

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	4.6.63	10.6.63	6	6,6	49,3	8,0	189	25,5	8,6
2	18.6.63	2.7.63	14	5,9	60,4	11,5	167	24,7	8,1
3	15.8.63	27.8.63	12	3,9	59,3	11,3	150	27,1	7,9
4	27.8.63	13.9.63	17	4,5	57,5	10,5	148	26,1	7,2
5	26.9.63	8.10.63	12	3,6	61,7	9,5	142	25,2	6,7
6	8.10.63	7.11.63	30	2,9	60,4	7,9	167	22,3	5,4
7	7.11.63	18.11.63	11	2,1	65,8	9,4	117	18,5	3,3
8	9.6.64	15.6.64	6	4,0	66,2	13,0	135	25,1	6,8
9	25.6.64	28.6.64	3	5,5	67,5	12,2	88	23,6	6,5
10	28.6.64	8.7.64	10	4,8	64,8	12,1	168	23,6	7,0
11	5.7.64	13.7.64	8	4,0	64,5	12,1	169	23,5	8,1
12	13.7.64	20.7.64	7	3,8	69,6	12,0	137	24,2	8,2
13	20.7.64	27.7.64	7	3,2	69,5	12,2	132	25,0	7,8
14	18.8.64	14.9.64	27	2,9	65,9	11,2	127	24,8	5,8
15	1.10.64	22.10.64	21	2,0	67,7	9,0	115	21,5	3,9
16	3.11.64	9.11.64	6	1,7	68,9	7,5	99	18,8	3,3
17	5.4.65	14.4.65	9	4,6	60,9	8,4	135	16,0	4,6
18	17.4.65	3.5.65	17	5,0	60,3	10,5	166	18,4	5,3
19	17.5.65	1.6.65	15	5,7	56,4	12,1	153	21,7	7,9
20	14.6.65	29.6.65	15	5,3	61,5	12,7	149	23,7	7,8
21	13.7.65	18.7.65	5	4,6	58,6	12,6	152	23,0	7,5
22	20.7.65	3.8.65	14	4,0	62,3	12,5	144	24,8	7,8
23	8.9.65	19.9.65	14	3,0	71,9	11,0	123	24,5	6,0
24	19.9.65	29.9.65	10	2,7	62,9	8,6	115	23,2	5,9
25	21.10.65	31.10.65	10	2,1	63,0	7,0	135	18,5	3,7
26	31.10.65	9.11.65	9	2,0	61,0	8,5	97	18,3	3,8



Table 3

- 13 -

Location: Saad  
 Crop: Grapes

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E <sup>o</sup> Class A pan mm/day
	From	to							
1	23.5.63	6.6.63	14	3,5	51,2	8,4	203	20,0	8,5
2	6.6.63	18.6.63	12	3,8	55,6	10,5	184	23,5	8,5
3	18.6.63	4.7.63	16	3,7	56,2	11,3	171	24,8	8,1
4	11.7.63	15.8.63	35	4,4	63,9	11,4	173	26,5	7,8
5	5.9.63	26.9.63	21	4,4	57,4	10,5	164	25,2	7,4
6	26.9.63	8.10.63	12	3,4	61,7	10,3	142	25,2	5,6
7	8.10.63	16.10.63	8	2,4	60,1	8,9	142	24,7	5,4
8	13.11.63	17.11.63	4	2,3	64,5	7,4	122	17,4	3,1
9	22.6.64	28.6.64	6	2,8	67,6	12,0	128	23,1	8,5
10	28.6.64	8.7.64	10	3,0	58,2	12,0	136	23,7	8,4
11	8.7.64	13.7.64	5	2,9	64,4	12,3	115	28,8	8,5
12	13.7.64	16.7.64	3	2,7	68,0	12,4	131	24,0	8,2
13	20.7.64	23.7.64	3	3,1	72,7	12,1	123	26,7	8,0
14	20.7.64	27.7.64	7	3,3	69,5	12,2	120	25,9	7,8
15	3.8.64	12.8.64	9	3,7	68,9	11,8	137	24,5	7,1
16	12.8.64	25.8.64	13	4,2	68,1	11,5	123	24,7	6,8
17	25.8.64	2.9.64	8	3,6	62,8	11,3	126	24,7	5,8
18	2.9.64	10.9.64	8	4,1	65,2	15,2	151	27,3	6,9
19	23.9.64	6.10.64	13	3,2	65,2	10,2	171	21,6	5,1
20	5.4.65	14.4.65	9	2,6	60,9	8,4	135	16,0	4,6
21	24.4.65	27.4.65	3	3,7	18,9	10,0	206	24,6	6,4
22	10.5.65	17.5.65	7	2,5	65,1	12,6	139	18,5	6,6
23	27.5.65	1.6.65	5	3,7	53,9	12,1	155	23,9	9,3
24	9.6.65	14.6.65	5	3,0	40,3	12,1	132	26,7	8,9
25	21.6.65	29.6.65	8	3,1	66,3	12,6	145	23,9	7,3
26	20.7.65	25.7.65	5	3,3	26,9	12,2	162	24,8	7,5
27	25.7.65	3.8.65	9	3,4	60,9	12,7	127	24,9	8,0
28	3.8.65	10.8.65	7	4,0	70,8	11,7	124	25,4	7,6
29	22.8.65	24.8.65	2	4,5	70,6	10,4	127	25,7	6,7
30	12.9.65	21.9.65	9	3,2	69,8	9,2	127	24,4	5,7
31	21.10.65	31.10.65	10	3,6	63,0	7,0	135	18,5	3,7
32	9.11.65	15.11.65	6	2,4	76,6	9,7	76	16,7	2,5



Table 4

- 14 -

Location: Saad  
 Crop: Cotton

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E <sup>o</sup> Class A pan mm/day
	From	to							
1	13.6.63	18.6.63	5	4,4	57,6	12,2	178	23,0	8,6
2	18.6.63	23.6.63	5	4,3	53,6	11,2	163	24,7	8,9
3	2.7.63	7.7.63	5	4,8	59,7	10,0	211	25,4	8,4
4	16.7.63	22.7.63	6	5,4	58,9	11,6	178	26,4	8,7
5	31.7.63	9.8.63	9	5,1	66,9	10,9	168	26,9	6,7
6	18.8.63	25.8.63	7	4,0	61,2	11,4	153	27,3	8,2
7	25.8.63	1.9.63	7	5,1	62,3	11,0	151	26,9	9,2
8	1.9.63	9.9.63	8	4,2	61,3	10,4	150	25,9	7,1
9	28.6.64	1.7.64	3	3,6	69,1	11,9	136	24,3	7,0
10	1.7.64	8.7.64	7	3,8	63,0	12,0	136	23,3	7,2
11	16.7.64	20.7.64	4	3,3	70,9	11,7	127	24,4	8,2
12	20.7.64	27.7.64	7	3,5	69,5	12,2	120	25,9	7,8
13	27.7.64	30.7.64	3	5,7	69,9	11,7	125	25,4	7,1
14	30.7.64	3.8.64	4	5,1	68,8	11,7	128	25,2	7,1
15	2.9.64	14.9.64	12	3,3	64,2	12,3	128	23,9	6,6
16	14.9.64	1.10.64	17	2,5	65,1	9,5	131	22,4	6,1
17	21.6.65	29.6.65	8	5,0	66,3	12,0	145	23,9	7,3
18	20.7.65	25.7.65	5	5,8	62,9	12,2	162	24,8	7,5
19	3.8.65	10.8.65	7	6,1	70,8	11,7	124	25,4	7,6
20	15.8.65	24.8.65	9	5,0	71,1	10,8	122	25,8	6,5
21	24.8.65	31.8.65	7	5,1	66,2	11,8	132	24,7	6,9
22	31.8.65	7.9.65	7	3,3	66,0	11,7	125	23,5	6,3
23	12.9.65	19.9.65	7	2,5	73,0	9,3	130	24,8	6,0



Table 5

Location: Nir Yitzhak

Crop: Alfalfa

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	4.4.63	16.4.63	12	5,6	55,3	8,4	259	18,5	5,6
2	16.5.63	21.5.63	5	7,0	49,3	10,6	158	18,5	8,3
3	6.6.63	13.6.63	7	6,8	53,4	9,4	171	23,9	8,5
4	19.6.63	25.6.63	6	7,4	63,9	11,2	150	23,2	7,3
5	28.7.63	29.7.63	1	7,0	67,3	12,0	147	26,0	9,5
6	29.7.63	5.8.63	7	7,4	68,6	10,6	142	27,1	8,6
7	9.8.63	17.8.63	8	7,9	62,7	11,2	143	27,3	8,07
8	1.10.63	8.10.63	7	6,5	67,3	10,3	113	24,9	5,7
9	12.10.63	24.10.63	12	5,5	64,9	7,0	130	24,4	4,6
10	26.4.64	29.4.64	3	5,3	52,7	7,3	118	20,5	6,0
11	6.5.64	24.5.64	18	5,6	52,7	11,5	129	18,2	6,5
12	3.6.64	14.6.64	11	6,2	49,2	13,3	133	23,8	8,4
13	14.6.64	24.6.64	10	7,0	64,1	12,3	126	21,2	7,0
14	5.7.64	12.7.64	7	6,0	56,4	12,3	141	24,4	7,7
15	12.7.64	26.7.64	14	6,2	66,1	12,3	129	21,3	7,3
16	26.7.64	2.8.64	7	5,7	65,0	11,5	120	25,6	7,0
17	2.8.64	3.9.64	30	5,4	68,7	11,3	122	26,1	7,4



Table 6

Location: Nir Yizthak  
 Crop: Peanuts

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	5.7.63	8.7.63	3	5,1	65,6	11,3	178	25,6	8,0
2	12.7.63	15.7.63	3	6,0	64,6	12,5	150	25,6	8,2
3	15.7.63	23.7.63	8	6,0	62,3	11,4	164	26,8	8,3
4	5.8.63	10.8.63	5	4,6	69,7	11,3	145	27,0	7,9
5	13.8.63	18.8.63	5	4,7	62,1	11,1	130	27,5	7,8
6	21.6.64	29.6.64	8	5,3	66,2	12,2	123	23,8	7,0
7	8.7.64	20.7.64	12	6,7	61,8	12,3	129	24,5	7,3
8	22.7.64	27.7.64	5	6,5	65,5	11,5	120	26,1	7,00
9	28.7.64	3.8.64	6	5,3	66,5	11,1	125	20,7	7,1
10	5.8.64	10.8.64	5	4,0	68,0	11,1	145	25,3	7,2
11	19.8.64	24.8.64	5	4,1	69,4	10,5	107	25,9	6,3
12	25.6.65	30.6.65	5	6,3	60,7	12,5	107	24,8	7,4
13	1.7.65	7.7.65	6	6,3	66,7	12,8	996	25,2	6,9
14	8.7.65	14.7.65	6	6,8	63,0	12,7	154	26,3	7,1
15	5.8.65	18.8.65	13	5,1	68,5	11,7	115	25,5	6,8
16	19.8.65	1.9.65	13	4,6	66,7	11,3	111	25,3	6,6
17	9.9.65	15.9.65	6	4,2	67,1	10,3	111	24,9	6,1



Table 7

Location: Nir Yizthak

Crop: Lemons

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	6.3.63	23.3.63	17	3,4	63,7	7,2	180	13,9	4,2
2	4.5.63	14.5.63	10	3,3	58,0	8,9	191	20,4	7,8
3	14.5.63	26.5.63	12	3,3	44,4	9,0	191	21,4	8,5
4	2.6.63	24.6.63	22	4,4	55,8	10,8	158	26,0	8,2
5	21.7.63	8.8.63	19	3,8	71,2	11,0	153	26,8	8,5
6	12.9.63	27.9.63	15	3,5	60,9	11,1	133	24,8	6,5
7	4.10.63	29.10.63	25	2,2	67,6	8,0	118	24,1	4,5
8	16.4.64	20.4.64	4	3,2	61,5	11,2	165	16,0	5,4
9	24.4.64	27.4.64	3	2,8	39,0	10,3	117	21,5	8,1
10	15.6.64	25.6.64	10	4,7	64,7	12,2	125	23,7	7,30
11	29.6.64	2.7.64	3	4,3	51,9	12,1	121	25,2	8,60
12	6.7.64	14.7.64	8	3,5	58,0	12,4	144	24,3	7,50
13	28.7.64	21.8.64	7	2,9	66,0	11,3	125	26,1	7,20
14	4.8.64	25.8.64	21	2,1	64,6	10,3	121	25,5	6,90
15	4.9.64	22.9.64	18	3,7	65,4	9,1	119	23,1	6,0
16	11.4.65	18.4.65	7	3,9	55,0	10,8	134	18,4	6,3
17	18.4.65	28.4.65	10	3,7	31,0	10,5	148	24,5	9,9
18	2.5.65	9.5.65	7	2,4	46,7	11,4	134	19,6	6,8
19	24.5.65	30.5.65	6	3,2	43,5	12,3	109	24,0	7,7
20	7.6.65	13.6.65	6	3,0	48,4	12,1	102	26,4	7,9
21	4.7.65	11.7.65	7	3,3	64,7	12,5	106	26,2	7,0
22	11.7.65	14.7.65	3	3,2	61,6	12,1	209	24,7	8,3
23	18.7.65	21.7.65	3	3,1	55,6	13,0	121	25,1	9,0
24	21.7.65	25.7.65	4	4,6	69,6	12,0	109	24,9	7,5
25	28.7.65	1.8.65	4	5,4	66,3	12,5	124	25,9	8,1
26	1.8.65	4.8.65	3	2,7	69,4	12,8	113	24,4	7,1
27	4.8.65	18.8.65	14	2,8	68,5	11,6	115	25,5	6,8
28	18.8.65	22.8.65	4	2,6	72,3	10,9	107	26,1	6,6
29	29.8.65	1.9.65	3	3,9	56,1	12,0	119	23,9	6,6
30	1.9.65	5.9.65	4	2,5	67,0	11,7	116	23,7	6,3
31	8.9.65	15.9.65	7	2,4	72,1	10,6	139	24,8	6,1
32	15.9.65	19.9.65	4	2,5	74,8	10,6	116	24,9	5,9
33	5.9.65	8.9.65	3	2,2	73,9	11,5	129	24,4	6,0



Table 8

Location: Nir Yizthak

Crop: Grapes

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	11.5.63	17.5.63	6	3,1	42,3	9,1	179	21,8	8,8
2	11.6.63	25.6.63	14	3,0	58,3	11,8	154	23,5	8,1
3	23.7.63	8.8.63	16	3,0	66,8	11,2	144	26,8	8,5
4	7.9.63	16.9.63	9	2,6	63,8	10,7	126	25,6	6,6
5	12.4.64	19.4.64	7	2,5	59,4	12,0	161	16,8	5,3
6	22.4.64	29.4.64	7	2,6	55,1	10,1	123	19,0	5,8
7	3.5.64	6.5.64	3	2,8	63,5	10,2	118	16,8	5,4
8	13.5.64	20.5.64	7	3,8	63,1	12,0	134	18,3	6,6
9	26.5.64	31.5.64	5	3,3	31,2	12,2	129	25,8	8,0
10	31.5.64	3.6.64	3	3,0	57,7	12,3	121	24,3	7,4
11	3.6.64	10.6.64	7	3,0	54,6	13,0	132	22,8	7,8
12	10.6.64	14.6.64	4	3,8	39,8	13,2	135	24,9	9,1
13	17.6.64	21.6.64	4	3,7	62,4	12,2	115	24,4	7,2
14	28.6.64	19.7.64	21	4,4	58,1	12,4	131	24,5	7,6
15	14.7.64	21.7.64	7	3,4	67,2	12,2	129	24,6	7,3
16	4.8.64	17.8.64	13	3,9	62,7	11,3	129	25,1	7,2
17	17.8.64	26.8.64	9	4,6	67,5	11,2	109	26,1	6,3
18	22.3.65	18.4.65	27	2,8	60,4	8,8	135	16,4	4,6
19	18.4.65	28.4.65	10	2,5	31,0	10,5	148	24,5	9,9
20	28.4.65	2.5.65	4	2,8	65,2	10,3	123	17,2	5,1
21	16.5.65	24.5.65	8	4,3	60,5	12,5	124	20,5	6,1
22	30.5.65	13.6.65	14	5,4	54,5	11,3	104	24,9	7,6
23	13.6.65	23.6.65	10	4,7	54,1	12,7	122	24,5	9,5
24	30.6.65	11.7.65	11	3,8	64,9	12,6	105	25,7	7,1
25	11.7.65	18.7.65	7	3,6	63,8	12,5	166	23,9	7,9
26	18.7.65	25.7.65	7	3,2	66,8	12,4	113	24,9	8,1
27	28.7.65	1.8.65	4	3,8	66,3	12,5	124	25,9	8,1
28	1.8.65	4.8.65	3	4,9	69,4	12,8	113	24,4	7,1
29	4.8.65	18.8.65	14	4,4	68,5	11,6	115	25,5	6,8
30	18.8.65	22.8.65	4	2,5	72,3	10,9	107	26,1	6,6
31	22.8.65	25.8.65	3	2,8	70,1	10,4	114	26,1	6,6
32	25.8.65	29.8.65	4	2,9	65,6	11,7	112	25,0	6,8
33	1.9.65	5.9.65	4	3,1	67,0	11,7	116	23,7	6,3
34	8.9.65	12.9.65	4	3,1	71,2	11,0	110	24,7	6,9
35	12.9.65	15.9.65	3	2,5	74,2	11,0	114	25,1	5,2
36	15.9.65	19.9.65	4	3,2	74,8	10,6	116	24,9	5,9



Table 9

Location: Nir Yizthak

Crop: Peach

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	24.3.63	27.4.63	34	3,3	54,5	8,3	208	19,1	6,0
2	15.5.63	20.5.63	5	5,4	46,9	10,5	153	18,8	7,9
3	12.8.63	1.9.63	20	5,4	63,7	11,2	136	27,1	7,6
4	6.4.64	13.4.64	4	2,6	52,1	8,3	168	16,5	6,0
5	27.4.64	4.5.64	7	4,2	63,3	9,4	155	16,9	5,7
6	11.5.64	14.5.64	3	4,2	58,6	11,8	101	17,3	6,4
7	14.5.64	21.5.64	7	4,0	63,3	12,0	137	18,7	5,5
8	21.5.64	25.5.64	4	3,4	64,2	11,7	127	14,7	6,6
9	25.5.64	28.5.64	3	3,8	44,8	12,3	120	21,6	8,2
10	8.6.64	11.6.64	3	4,5	52,9	13,2	135	23,6	8,4
11	18.6.64	22.6.64	4	5,3	65,1	12,2	123	23,9	7,2
12	6.7.64	13.7.64	7	6,6	57,8	12,3	144	24,5	7,5
13	21.7.64	28.7.64	7	6,0	56,4	12,5	110	25,8	6,6
14	26.8.64	23.9.64	28	5,0	64,3	13,4	112	23,0	6,3
15	23.9.64	9.10.64	16	3,5	63,6	12,2	110	20,4	5,2
16	11.4.65	18.4.65	7	5,1	55,0	10,8	134	18,4	6,3
17	18.4.65	28.4.65	10	5,6	31,0	10,5	148	24,5	9,9
18	24.5.65	7.6.65	14	5,7	53,1	12,3	107	23,8	7,5
19	30.6.65	11.7.65	11	5,6	52,9	12,6	105	25,7	7,2



Table 10

Location: Kefar Havarok  
 Crop: Plums

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	13.4.64	23.4.64	10	4,3	69,0	10,5	230	14,9	4,9
2	12.6.64	21.6.64	9	6,2	66,3	12,0	200	23,2	8,1
3	1.7.64	14.7.64	13	3,0	65,7	12,4	205	24,5	7,3
4	22.7.64	6.8.64	15	3,6	70,8	11,4	190	23,5	7,1
5	3.9.64	9.9.64	6	3,8	67,2	10,3	176	24,7	6,3
6	22.9.64	29.9.64	7	3,3	68,3	8,0	194	23,1	6,2
7	8.10.64	15.10.64	7	2,2	65,7	9,6	169	21,8	4,4
8	28.10.64	12.11.64	15	2,1	65,2	8,3	146	19,5	5,6
9	7.4.65	15.4.65	8	4,8	55,5	7,2	179	17,6	5,4
10	29.4.65	7.5.65	8	3,5	61,0	9,6	222	18,4	5,9
11	4.6.65	10.6.65	6	5,0	69,6	11,1	172	23,7	8,1
12	15.7.65	19.7.65	4	5,7	64,6	12,0	199	24,5	7,9
13	22.7.65	26.7.65	4	6,2	75,6	10,9	172	24,8	7,0
14	26.7.65	29.7.65	3	5,2	67,0	12,0	183	25,2	7,6
15	29.7.65	2.8.65	4	5,1	66,0	11,3	176	26,3	7,3
16	19.8.65	26.8.65	7	5,6	66,5	10,8	184	26,3	8,0
17	26.8.65	30.8.65	4	3,9	55,5	11,0	194	25,4	8,2
18	30.8.65	6.9.65	7	3,6	59,4	10,9	183	24,6	6,8
19	13.9.65	20.9.65	7	2,4	71,2	8,9	191	25,5	6,1
20	19.10.65	28.10.65	9	2,3	58,3	8,2	190	19,9	4,2
21	28.10.65	11.11.65	14	2,8	56,5	8,4	151	19,5	4,1



Table 11

Location: Kefar Hayarok

Crop: Oranges

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km /day	Mean daily temp. °C.	E° Class A pan mm/day
	From	to							
1	6.4.64	14.4.64	17	2,0	68,2	10,5	252	15,7	4,7
2	27.5.64	2.6.64	6	3,4	56,2	12,0	195	25,4	11,3
3	17.6.64	24.6.64	7	3,6	70,2	11,6	199	23,5	7,7
4	24.6.64	20.7.64	26	4,1	67,5	12,1	198	24,3	7,4
5	20.7.64	13.8.64	24	3,9	70,3	11,5	184	25,0	7,1
6	17.9.64	24.9.64	7	2,5	63,7	10,1	172	23,4	5,9
7	24.9.64	29.9.64	5	1,7	56,5	9,4	193	22,9	6,3
8	7.4.65	15.4.65	8	2,6	55,5	7,2	179	17,6	5,4
9	13.5.65	21.5.65	8	2,9	64,3	11,8	250	20,3	7,3
10	15.7.65	22.7.65	7	3,0	69,7	12,2	189	24,6	8,0
11	22.7.65	2.8.65	11	3,1	66,8	11,2	176	25,5	7,3
12	12.8.65	16.8.65	4	3,9	62,2	11,6	196	25,9	8,3
13	16.8.65	23.8.65	7	3,9	67,8	10,5	180	26,2	7,3
14	30.8.65	2.9.65	3	3,9	51,3	11,4	196	24,2	7,7
15	13.9.65	20.9.65	7	3,1	71,2	8,9	191	25,5	6,1
16	20.9.65	30.9.65	10	3,6	66,3	9,5	176	23,7	5,8
17	29.10.65	7.11.65	9	2,3	46,1	8,5	157	20,1	4,3



Table 12

Location: Kefar Hayarok  
 Crop: Grapefruit

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	5.5.64	13.5.64	8	3,4	64,9	10,7	240	17,4	6,1
2	13.5.64	26.5.64	13	2,8	66,0	11,7	224	17,6	6,8
3	25.6.64	13.8.64	49	4,1	68,9	11,8	192	24,7	7,2
4	19.8.64	3.9.64	15	2,8	66,0	11,5	188	25,1	7,00
5	29.9.64	8.10.64	9	2,7	53,7	9,5	225	19,3	6,4
6	8.10.64	15.10.64	7	2,3	65,7	9,6	169	21,8	4,4
7	7.4.65	15.4.65	8	2,9	56,5	7,2	179	17,6	5,4
8	15.4.65	29.4.65	14	2,3	55,2	9,6	189	20,4	5,7
9	7.5.65	13.5.65	6	3,0	60,0	12,1	184	16,8	6,4
10	13.5.65	20.5.65	7	2,4	63,6	12,0	269	19,8	6,9
11	16.6.65	28.6.65	12	3,2	62,1	9,7	196	23,9	8,0
12	15.7.65	22.7.65	7	2,3	69,7	12,2	189	24,6	8,0
13	26.7.65	2.8.65	7	4,6	66,5	11,4	179	25,8	7,5
14	12.8.65	19.8.65	7	5,1	64,2	11,5	188	26,0	7,9
15	19.8.65	23.8.65	4	4,0	68,5	10,2	181	26,3	7,3
16	30.8.65	6.9.65	7	2,7	59,4	10,9	183	24,6	6,8
17	16.9.65	30.9.65	14	2,1	66,7	8,5	176	24,1	5,8
18	19.10.65	29.10.65	10	3,6	56,8	8,2	185	19,8	4,5
19	29.10.65	7.11.65	9	3,1	46,1	8,5	157	20,1	4,3



Table 13

Location: Kefar Hayarok

Crop: Grape

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km /day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	19.4.64	4.5.64	15	1,8	60,0	11,0	215	17,1	6,3
2	4.5.64	10.5.64	6	1,8	63,5	11,1	222	17,7	6,3
3	21.5.64	31.5.64	10	2,8	60,0	13,0	206	22,5	9,2
4	31.5.64	10.6.64	10	1,8	66,6	12,3	216	22,1	7,4
5	18.6.64	2.7.64	14	3,8	69,4	11,5	143	23,9	7,5
6	14.7.64	19.8.64	34	1,9	73,3	11,8	195	25,7	7,6
7	14.8.64	24.8.64	5	2,0	70,7	11,3	173	25,5	6,3
8	24.9.64	29.9.64	5	1,8	57,6	9,4	193	23,0	6,3
9	15.10.64	28.10.64	13	2,2	61,9	9,2	164	22,2	5,1
10	7.4.65	15.4.65	8	1,6	55,5	7,2	179	17,6	5,4
11	15.4.65	29.4.65	14	2,8	55,2	9,6	189	20,4	5,7
12	7.5.65	13.5.65	6	2,2	60,0	12,1	184	16,8	6,4
13	20.5.65	2.6.65	13	2,2	69,4	10,2	164	22,0	6,1
14	2.6.65	15.6.65	13	3,2	69,7	10,4	183	24,6	8,4
15	15.6.65	28.6.65	13	2,7	62,0	9,7	197	23,9	8,0
16	19.7.65	2.8.65	14	4,5	70,4	11,5	176	25,3	7,5
17	23.8.65	30.8.65	7	4,8	59,1	11,2	192	25,7	6,8
18	6.9.65	16.9.65	10	4,2	71,3	9,8	175	24,9	6,9
19	13.9.65	20.9.65	7	3,6	71,2	8,9	191	25,5	6,1
20	19.10.65	3.11.65	15	2,3	55,6	8,4	184	19,5	4,4
21	3.11.65	7.11.65	4	3,0	43,0	8,1	126	21,9	4,4



Table 14

Location: Kefar Hayarok  
 Crop: Apples

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km/day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	7.4.65	15.4.65	8	3,9	55,5	7,2	179	17,6	5,4
2	10.6.65	15.6.65	5	5,3	58,1	9,3	201	27,0	9,1
3	12.7.65	15.7.65	3	5,0	54,3	11,9	304	24,5	6,8
4	15.7.65	22.7.65	7	4,6	69,7	12,2	189	24,6	8,0
5	12.8.65	16.8.65	4	3,5	62,2	11,6	196	25,9	8,3
6	30.8.65	6.9.65	7	3,7	59,4	10,9	183	24,6	6,8
7	20.9.65	19.10.65	39	2,4	62,5	8,6	167	22,8	4,8
8	19.10.65	28.10.65	9	2,5	58,3	8,4	190	19,9	4,2
9	3.11.65	7.11.65	10	3,0	43,0	8,1	126	21,9	4,4
10	7.11.65	16.11.65	9	2,5	69,6	8,2	150	17,7	2,9



Table 15

Location: Yotvata  
Crop: Grape

No.	Date		Days	E.T. mm/day	Relative humidity %	Direct sunlight hrs/day	Wind Km /day	Mean daily temp. °C	E° Class A pan mm/day
	From	to							
1	21.2.65	3.3.65	10	3,1	42,8	10,0	170	16,2	6,4
2	4.3.65	21.3.65	17	4,4	26,1	8,6	220	19,7	8,5
3	22.3.65	4.4.65	12	5,4	37,1	7,9	171	18,7	6,4
4	6.4.65	22.4.65	16	6,0	29,0	6,3	203	21,4	10,2
5	25.4.65	4.5.65	9	5,9	29,4	8,9	222	24,6	11,2
6	7.5.65	16.5.65	9	5,8	26,2	11,4	196	23,6	10,3
7	17.5.65	21.5.65	4	8,3	24,3	11,5	302	25,2	12,5
8	24.5.65	4.6.65	11	6,9	20,0	11,2	212	30,2	15,0
9	12.7.65	22.7.65	10	7,3	25,2	11,6	197	30,7	14,5
10	25.7.65	4.8.65	10	6,1	20,2	11,7	155	32,3	13,8
11	5.8.65	16.8.65	11	5,2	23,9	11,3	228,0	31,2	15,0
12	18.8.65	5.9.65	18	5,0	32,0	11,2	235	30,5	12,3
13	16.9.65	26.9.65	10	4,5	38,9	9,7	197	29,9	9,9



The data in the tables for the different crops are presented according to periods and include the following information:

1. period studied
2. average daily evapotranspiration for the period -  $E_t$  in whole numbers including the first digit after the decimal point.
3. average daily temperature, in degree Centigrade -  $T$  in whole numbers including the first digit after the decimal point.
4. average relative humidity, in percent -  $H$  in whole numbers including the first digit after the decimal point.
5. daily wind distance, in kilometers -  $W$  in whole numbers including the first digit after the decimal point.
6. average daily hours of sunshine -  $S$  in whole numbers including the first digit after the decimal point.
7. daily evaporation from Class A evaporation pan.

The data in the tables (excluding the Class A measurements) served as a basis for calculating the general equation. The evaporation can be used at a later stage for comparison with similar existing equations, in two forms: a) calculation of pan evaporation according to climatological factors, and b) calculation of evapotranspiration by means of evaporation data.

The first step in processing the data to calculate the general equation was to construct the following curves:

1. the consumptive water use of the crop vs. various climatic factors
2. the consumptive water use of one crop vs. the consumptive water use of each of the other crops.

Each figure contains data for one crop in a certain region for each of the years studied, with each month indicated separately. Examples of the curves are shown in Figures 1-8. The figures show that crop type and season



Fig. 1 The evapotranspiration vs. temperature fluctuations in the different years and months.

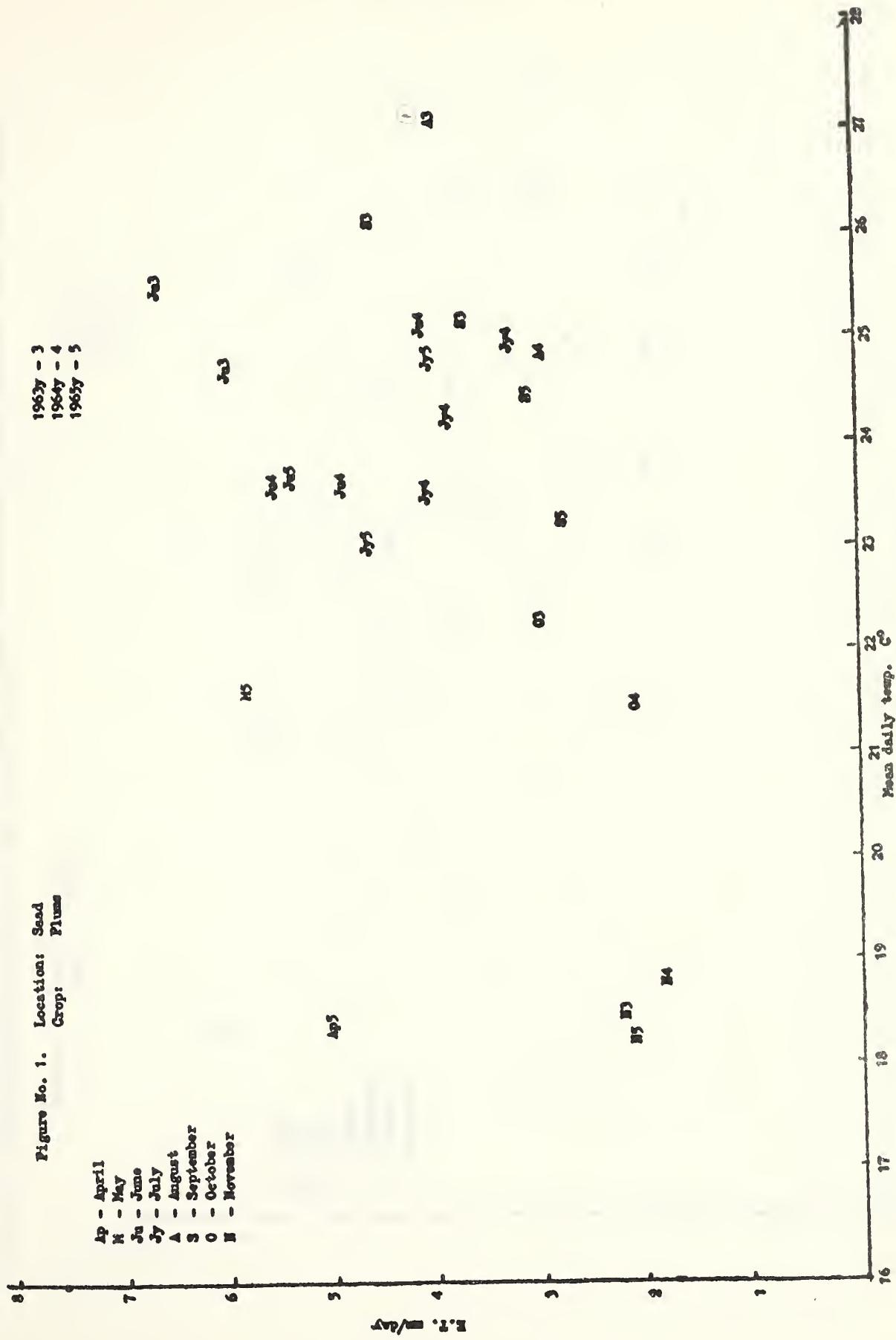




Fig. 2 The evapotranspiration vs. the relative humidity fluctuations in the different years and months.

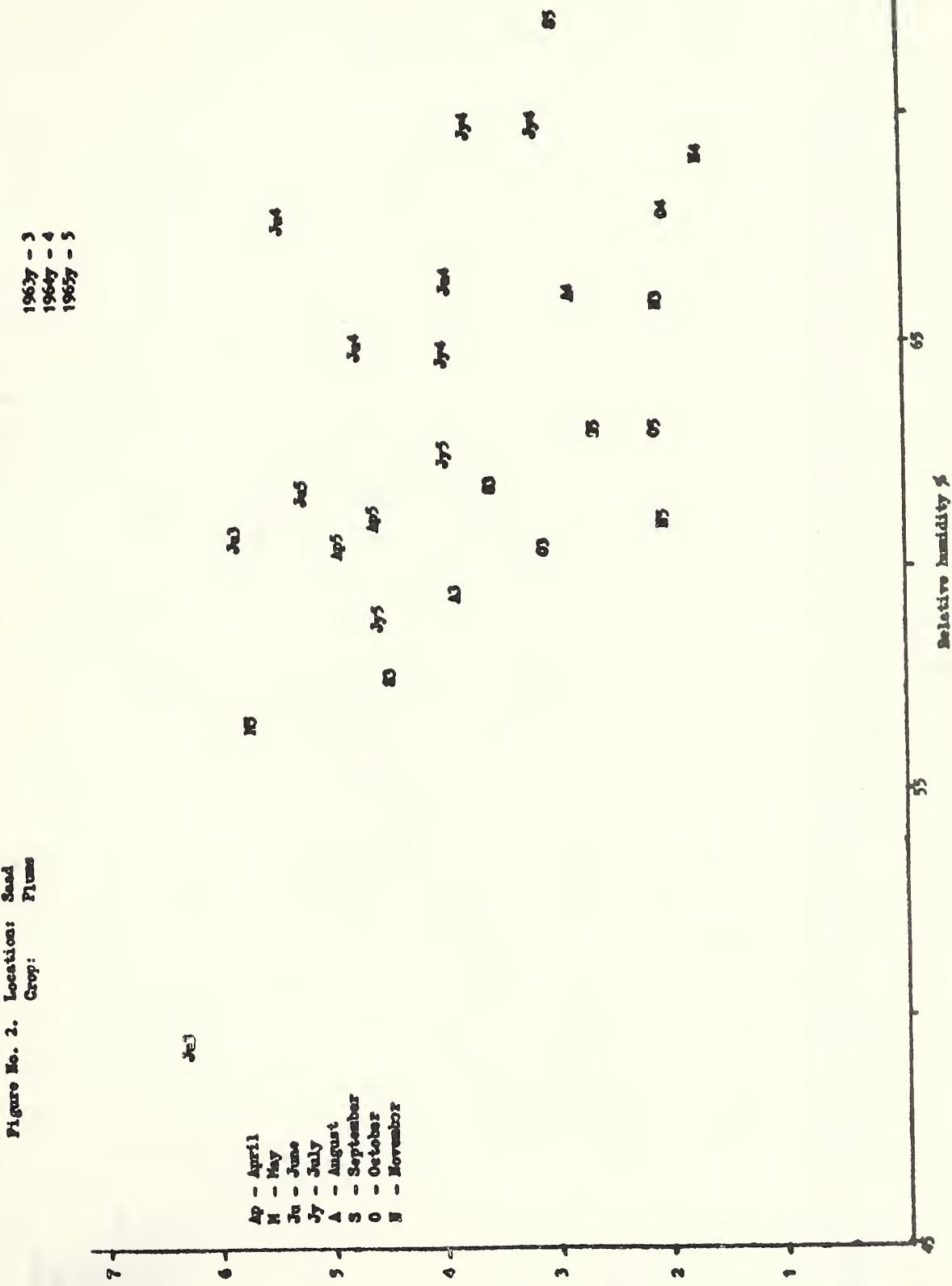




Fig. 3 The evapotranspiration vs. the wind fluctuations in the different years and months.

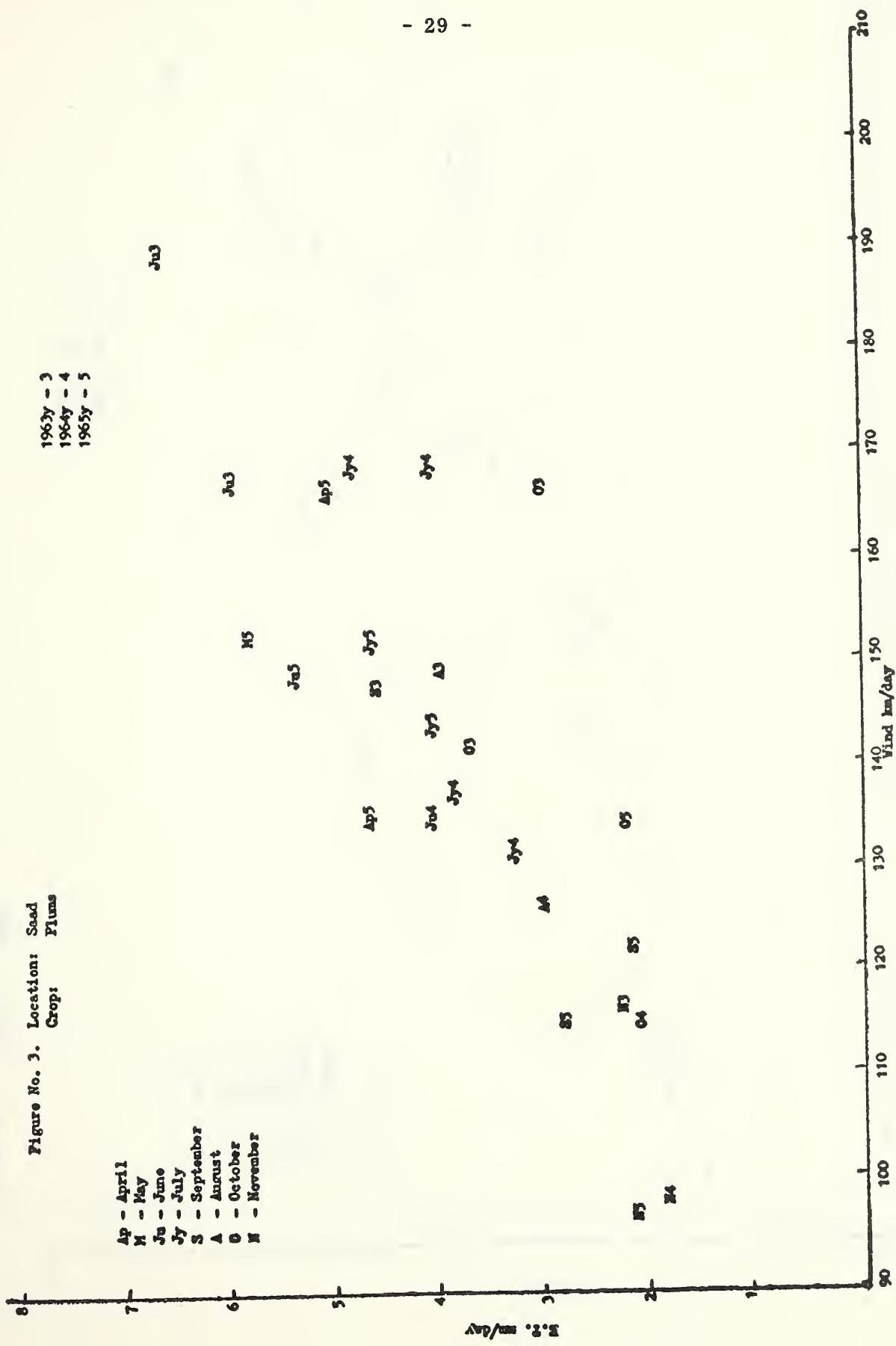




Fig. 4 The evapotranspiration vs. class a pan evaporation fluctuations in the different years and months.

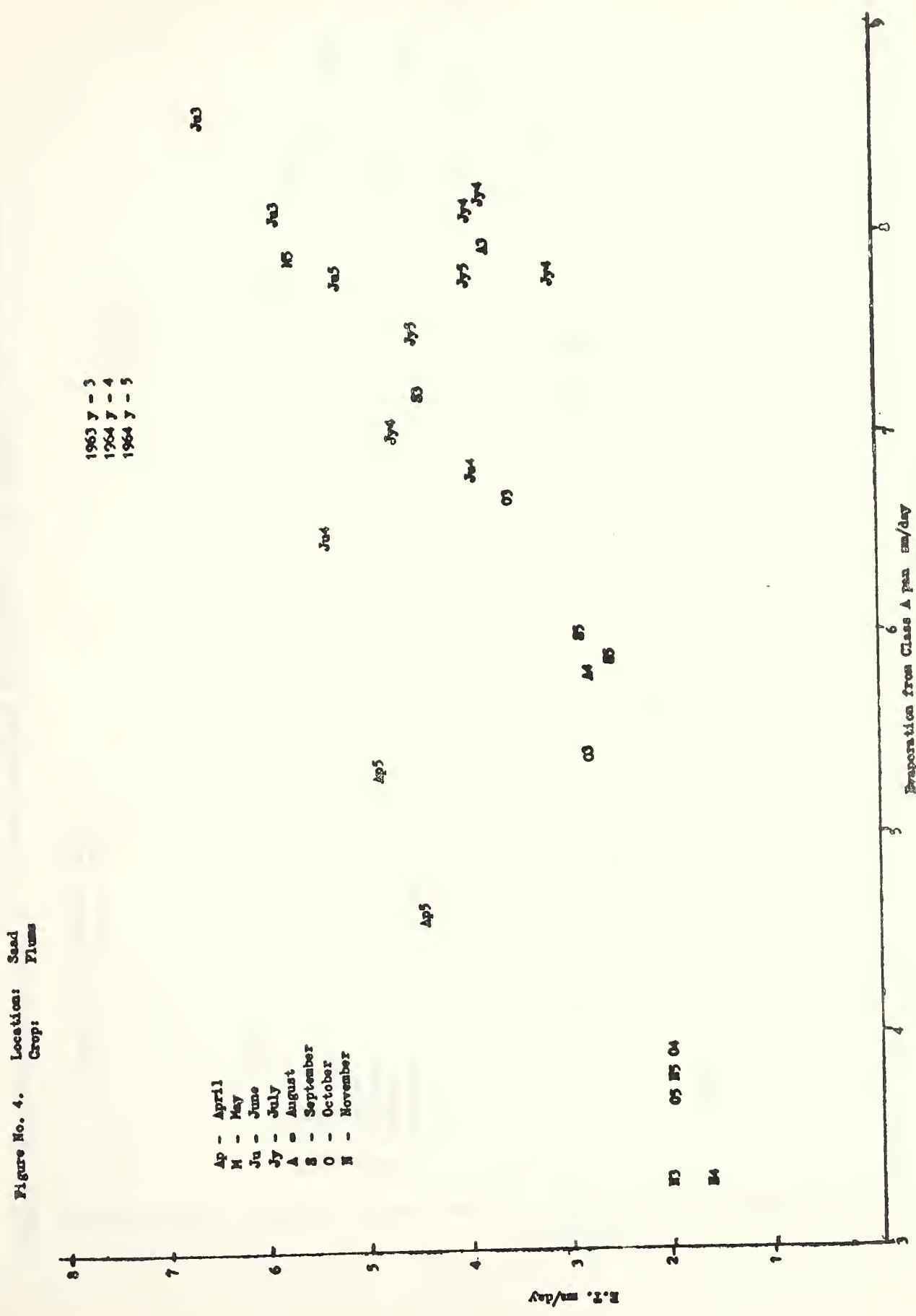




Fig. 5. The evapotranspiration vs. direct sunlight fluctuations in the different years and months.

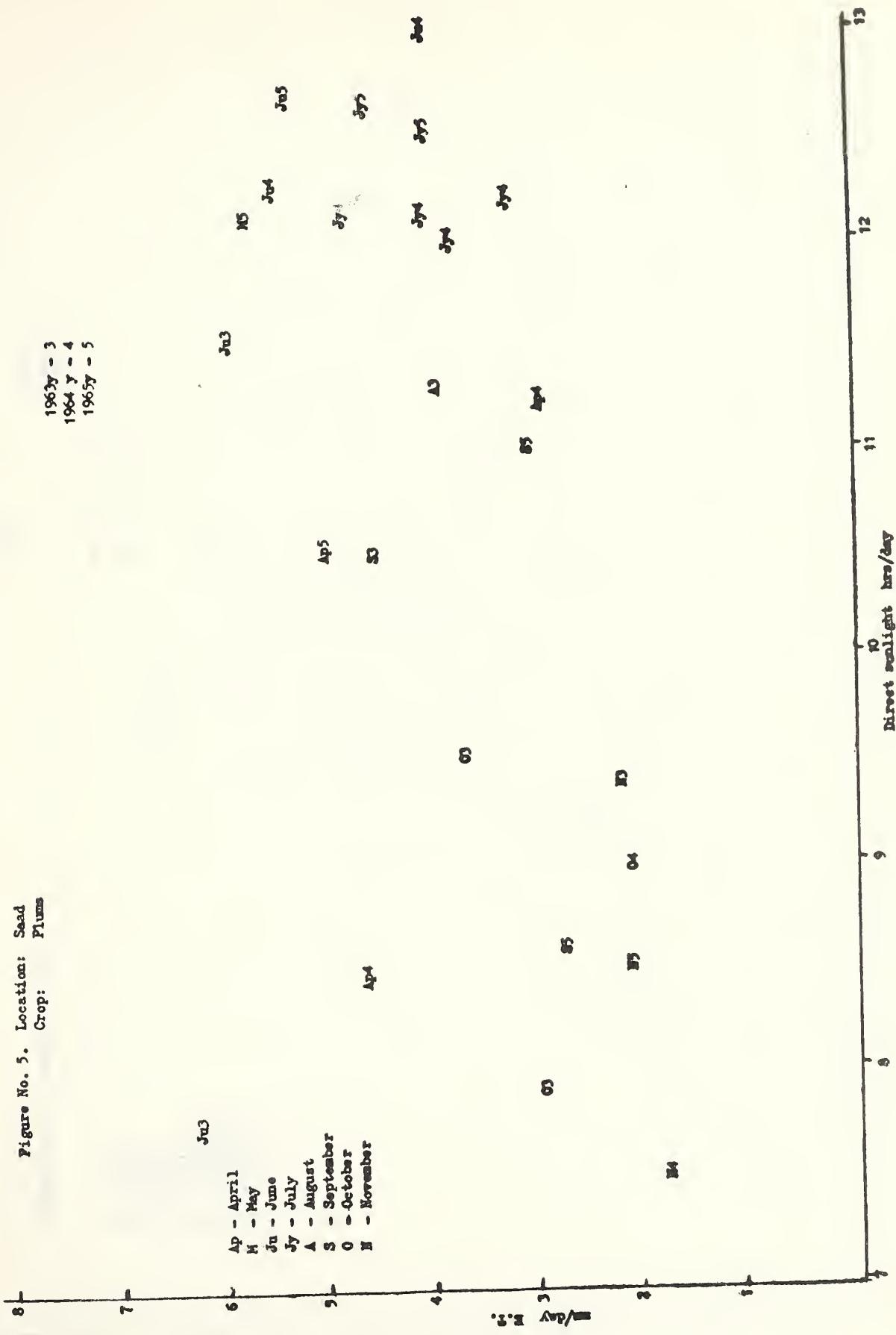




Fig. 6. Evapotranspiration from plums vs. evapotranspiration from vineyard

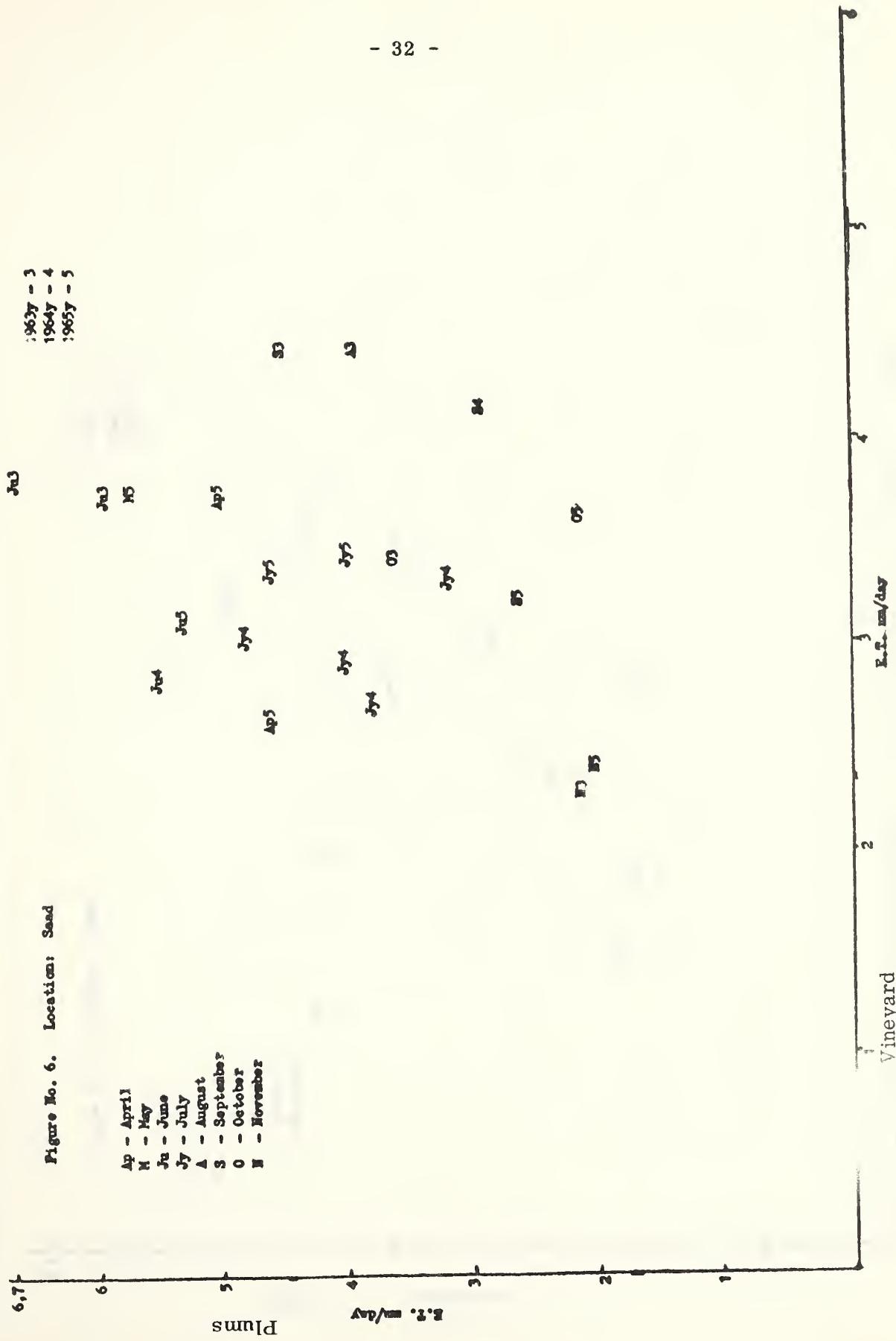




Fig. 7. The evapotranspiration from plums vs. evapotranspiration from apples.

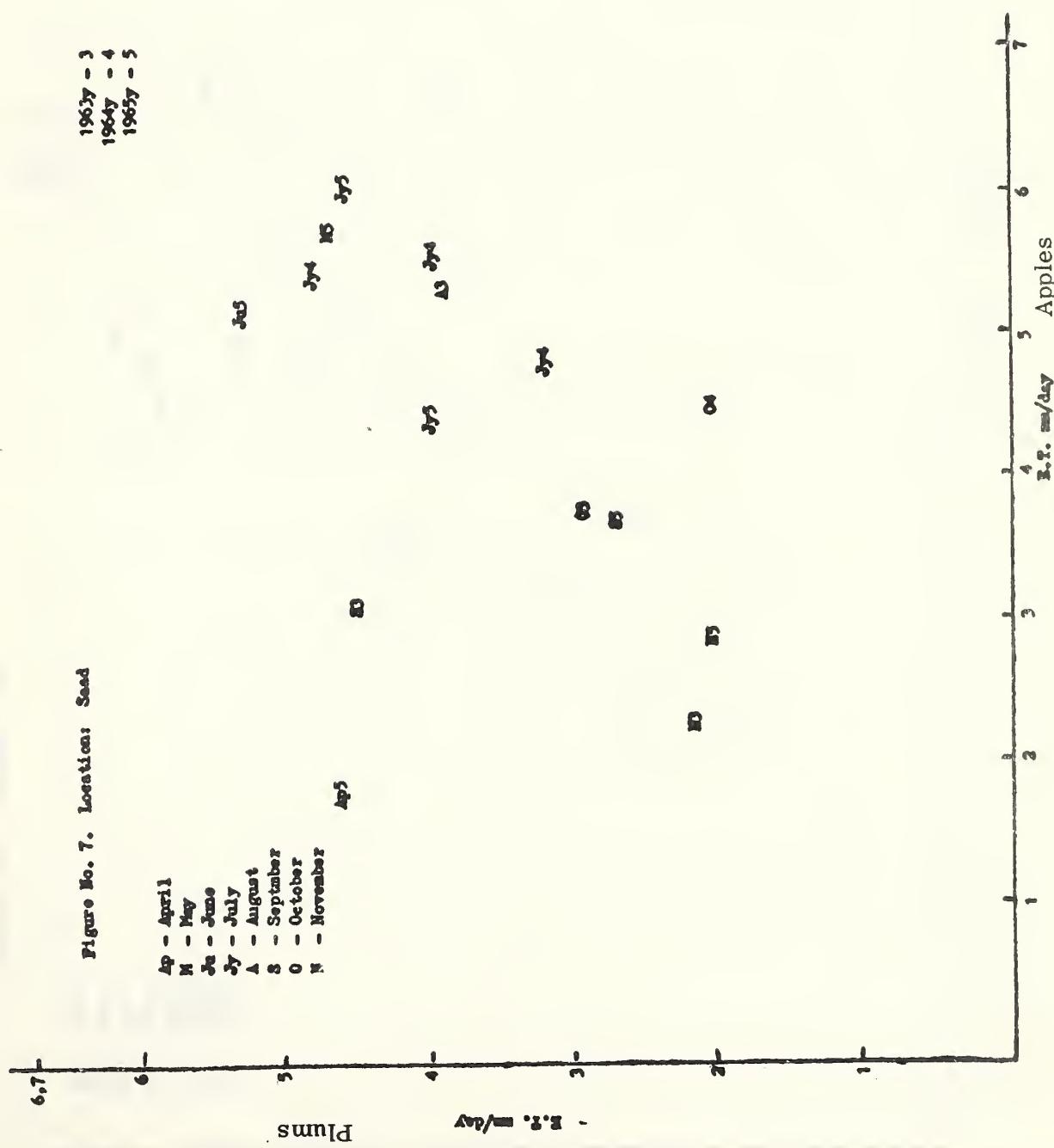
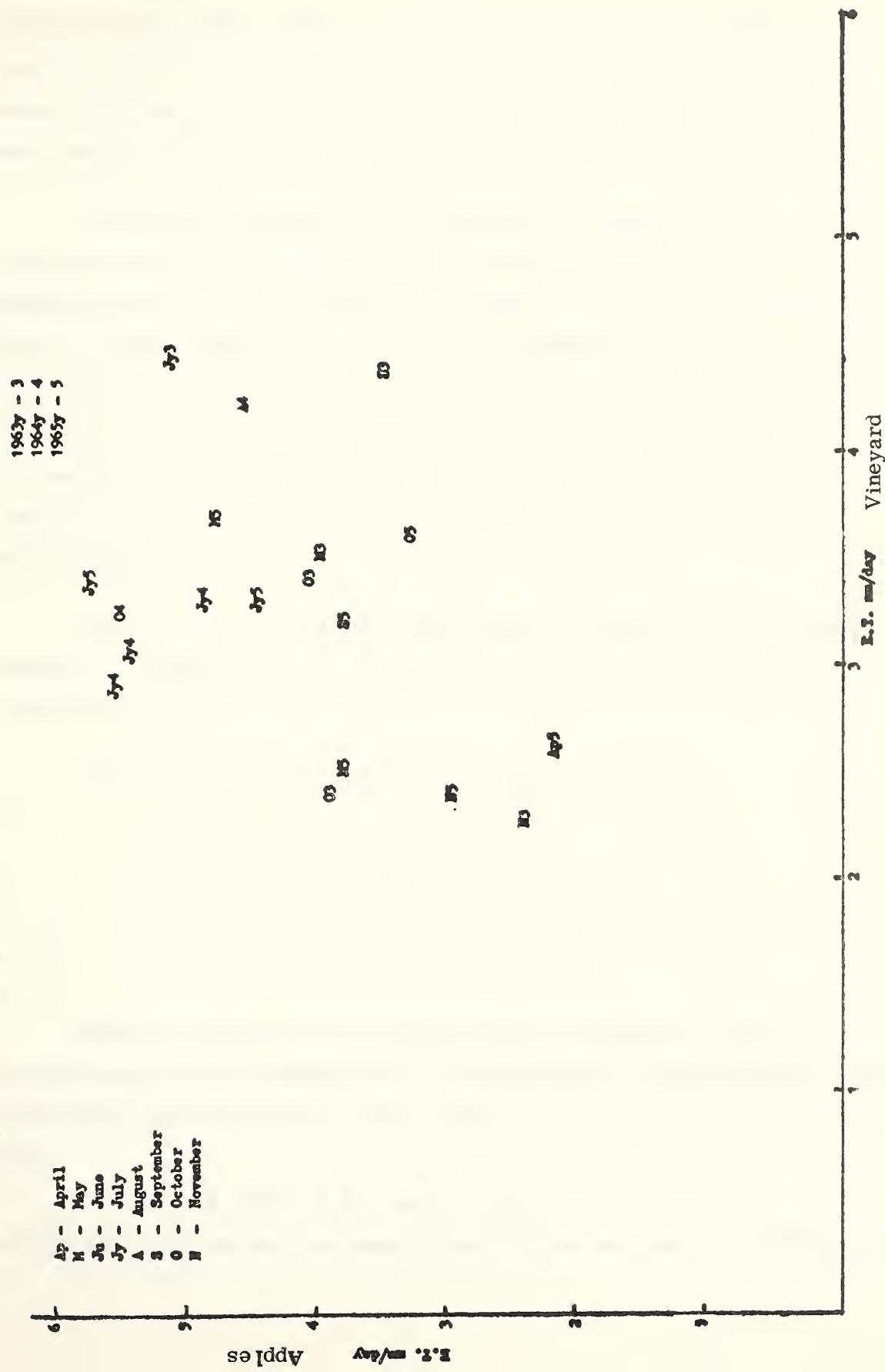




Fig. 8. The evapotranspiration from Apples vs. evapotranspiration from Vineyard.

Figure No. 8. Location: Sead





of the year have marked effects on the relation between evapotranspiration and climatic factors. It seems that the same plant reacts differently from one season to the next under the same climatic conditions (Figures 1-5), and other plants behave differently under similar climatic conditions (Figures 6-8).

Particularly interesting is the recurring phenomenon in some of the crops of a change in the relation between evapotranspiration and a certain climatic factor in a cyclic manner. For example, in Figure 1 the evapotranspiration increases from April to May, and occasionally to June, as the temperature rises. In July, with the same temperature, the transpiration decreases and continues to do so during August and September. During October and November when the temperature is similar to that in April, the cycle is completed with a much lower evapotranspiration rate. A similar pattern is seen in Figures 3, 4 and 5.

On the basis of the picture obtained from these figures, it was decided to combine in the general equation the following two factors: 1. crop type, and 2. season of the year.

Thus, the year was divided into 4 seasons, accordingly:

First season: April - May (Spring)

Second Season: June - July (Early Summer)

Third season: August- September (Late Summer)

Fourth season: October- November (Fall)

Similarly, the figures show that the nature of the general equation must be multiplicative and not additive when climatic factors or the plant factor do not contribute any constant additional value. Thus, it is possible to state in general terms.

$$Et = KM \cdot f (a_1 T + a_2 H + a_3 W + a_4 S)$$

and to facilitate calculations, the general equation has been given the following form.



The preliminary general equation had the following form:

$$\text{Log Et} = KM + a_1 T + a_2 H + a_3 W + a_4 S$$

where

a = coefficient

KM = constant for a certain crop and a certain season

#### Method of Calculation

To calculate the multiple regression, data from Saad were used from 1964 and 1965 for the following crops: apples, plums, grapes and cotton. The climatic coefficients  $a_1$ ,  $a_2$ ,  $a_3$ , and  $a_4$  were computed from all the data, while the crop constant, KM, was calculated separately for each crop and season.

The calculation resulted in an equation with the following climatic coefficients:

$$\begin{aligned}\text{Log Et} = KM &+ 0.0011529751T - 0.000097455975H \\ &+ 0.00066729054W + 0.0021551099 S\end{aligned}$$

The crop constants, KM, obtained were:

<u>Season</u>	<u>Apples</u>	<u>Plums</u>	<u>Grapes</u>	<u>Cotton</u>
Apr. - May	1) 1.043633	5) 1.224279	9) 0.958378	
June - July	2) 1.128434	6) 1.058035	10) 0.899247	13) 1.075189
Aug. - Sept.	3) 1.116055	7) 0.940860	11) 1.027056	14) 1.038065
Oct. - Nov.	4) 1.115873	8) 0.882960	12) 1.050581	

The preliminary results have been examined in three stages:

- evapotranspiration values as calculated from the equation have been compared with the evapotranspiration values used to establish the equation. Fig. 9.
- evapotranspiration values for those 1963 crops at Saad not included in the calculation of the equation have been compared with values computed with the equation. Fig. 10.



Fig. 9. Evaporation values as calculated from the Equation vs. the Evapotranspiration values to establish the Equation.

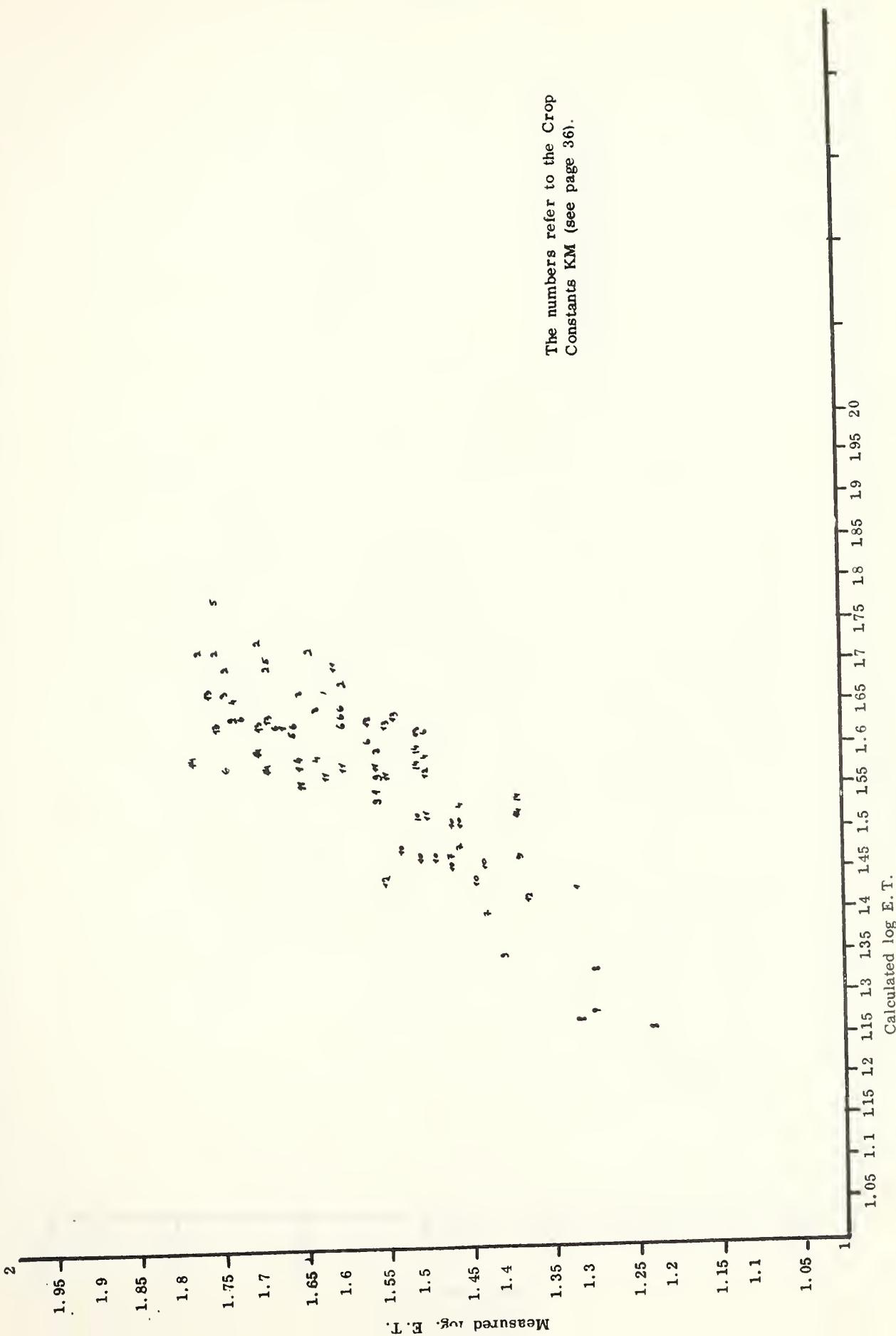




Fig. 10. Calculated values of the year 1963 vs. Evapotranspiration values of the same year.

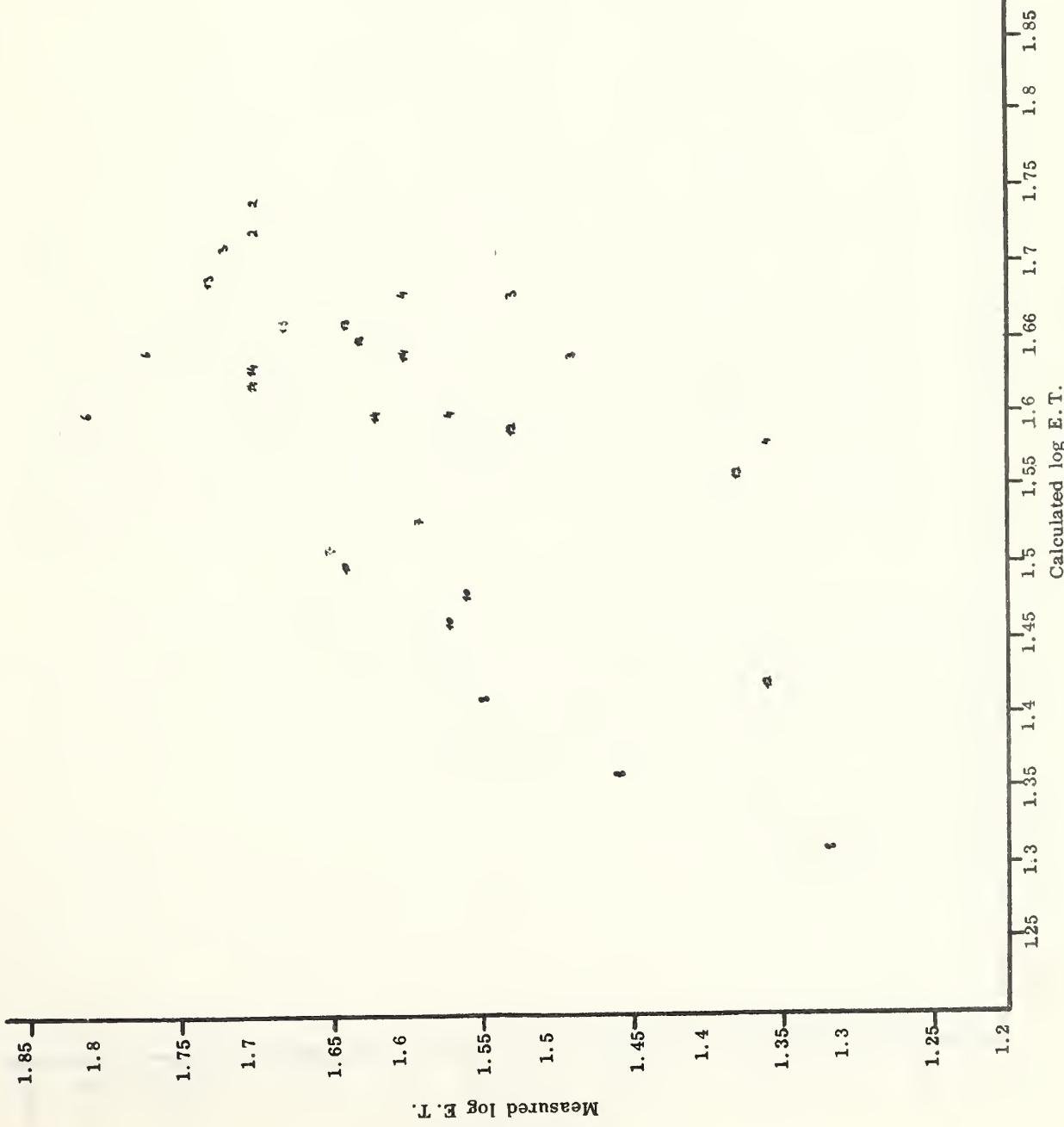
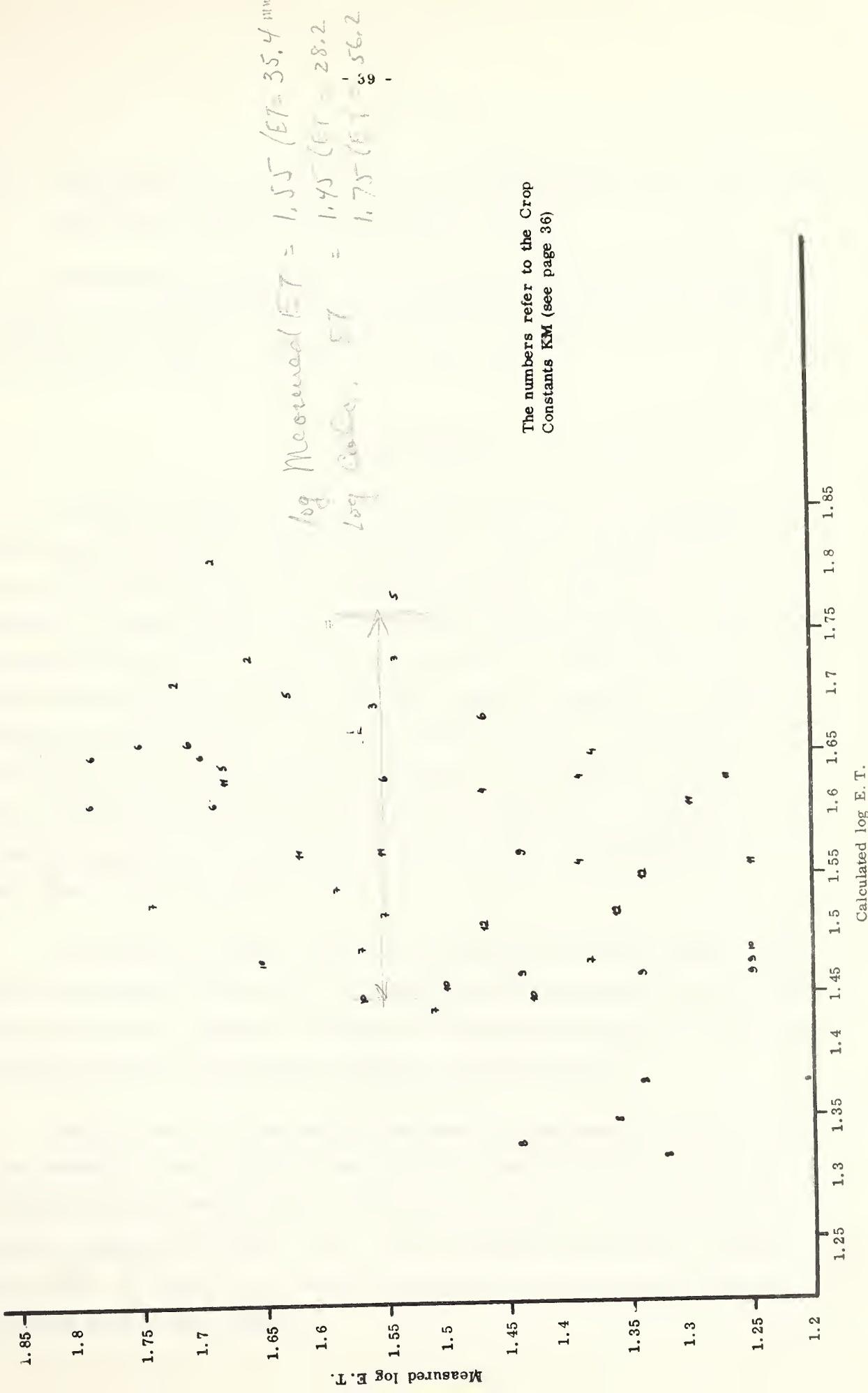




Fig. 11. Calculated values for Crops from other locations vs. measured values from the same locations





- c) evapotranspiration values for crops from other locations have been compared with values computed with the equation. Fig 11.

By using these comparisons it was possible to determine the degree of accuracy of the method and the reliability of the crop constants, and to consider any desirable changes in the structure of the equation.

### DISCUSSION

As seen in Figures 9 - 11, the calculated values are very close to the data used to calculate the equation (Figure 9). They are quite close to the actual values of the 1963 year for most of the crops (Figure 10), but are not suitable for those same crops in regions other than those where the evapotranspiration was calculated. From this one can learn the effect of each individual region under the same climatic conditions. The main source of the regional effect on evapotranspiration is in the variable soil types, and consequently in the frequency of irrigation and the magnitude of water applied to the crop. Thus, not taking into account the regional soil factors and irrigation practices results in a certain unavoidable error in estimating evapotranspiration from only climatic and crop data.

An attempt was made to calculate by the same method the climatic and plant coefficients of each region. In most cases the coefficients were similar but not identical. Therefore, all the data from all the regions were collected and one general regression was calculated for all the values.

The final result of the multiple regression is presented in Table 16. The five variables were as follows: temperature, relative humidity, wind, hours of radiation, and evapotranspiration (the dependent variable). The constant is the general constant of the plant, and it varies according to the type of crop and the season. In Table 17 are given the deviations from the average constant for each crop in each season.



THE GENERAL EQUATION

Table 16. The Multiple Regression and the Statistical Analysis

VAR	CCEFF	STD ERR	MEAN	VALUE 'T'
( 1 ) 1	0.12123132E-02	0.30705123E-03	0.23099981E C3	3.948
( 2 ) 2	-0.11880550E-03	0.80829429E-04	0.61677537E C3	-1.470
( 3 ) 3	-6.39456985E-04	0.97556020E-04	0.15352780E 03	-0.405
( 4 ) 4	0.12469969E-02	0.43653743E-03	0.10900923E 03	2.857
( 5 ) 5			DEPENDENT 0.15633249E 01	
RSQ=	0.113334			
CONST=	0.12271823E 01	STD ERR CF CCNST=	0.69335271E-01	VALUE 'T'= 17.699
RESIDUAL VARIANCE=	0.84753828E-02			
HYPOTHESIS J=0.	VALUE 'F' ( 282, 34 )=			13.497
RESIDUAL ST ERR=	0.92061842E-01			



Table 17 Deviations from the average Constant.

J GROUPS	DEV. OF CONST	STD ERR	GROUP SIZE	Crop	Season
1	-4.04124440E-01	0.41802239E-01	6.	Apples	April May
2	0.10830161E 00	0.27896967E-01	13.	Apples	June July
3	0.23023281E-01	0.33009651E-01	9.	Apples	August September
4	0.97771636E-02	0.30520086E-01	12.	Apples	October November
5	0.17721944E 00	0.43329046E-01	6.	Plums	April May
6	0.87771695E-01	0.233321956E-01	19.	Plums	June July
7	-0.49991915E-02	0.28932985E-01	12.	Plums	August September
8	-0.13863443E 00	0.32045195E-01	11.	Plums	October November
9	-0.95494685E-01	0.25209174E-01	22.	Grapes	April May
10	-C.75791467E-01	C.18419128E-01	32.	Grapes	June July
11	-0.51717465E-01	0.20862472E-01	27.	Grapes	August September
12	-0.70216488E-01	0.39006894E-01	7.	Grapes	October November
13	0.92317642E-01	0.35329031E-01	10.	Peach	April May
14	0.13746167E 00	0.40891460E-01	6.	Peach	June July
15	0.74023248E-01	0.56850705E-01	3.	Peach	August September
16	-0.24430361E-01	0.36352524E-01	9.	Lemon	October November
17	-0.20303371E-01	0.30582959E-01	11.	Lemon	April May
18	-0.13942869E 00	C.29528100E-01	12.	Lemon	June July
19	-0.19171716E 00	0.99009228E-01	1.	Lemon	August September
20	-0.87345900E-01	0.50410049E-01	4.	Orange	October November
21	-0.36265905E-01	0.44763019E-01	5.	Orange	April May
22	-0.77302559E-01	0.37545094E-01	7.	Orange	June July
23	-0.15415848E 00	0.99721135E-01	1.	Orange	August September
24	-0.55876958E-01	0.43063628E-01	6.	Grapefruit	October November
25	-0.45402433E-01	0.49585926E-01	4.	Grapefruit	April May
26	-0.77631094E-01	0.44569046E-01	5.	Grapefruit	June July
27	-0.50804914E-01	0.50716367E-01	4.	Grapefruit	August September
28	0.55620153E-01	0.30128878E-01	11.	Cotton	October November
29	0.28019482E-01	0.20553950E-01	12.	Cotton	April May
30	0.18395768E 00	0.32665557E-01	10.	Peanuts	June July
31	0.54886224E-01	0.32699533E-01	7.	Peanuts	August September
32	0.26105669E 00	0.51818727E-01	4.	Alfalfa	October November
33	0.23025186E 00	0.34820457E-01	8.	Alfalfa	April May
34	0.22757061E 00	0.58043301E-01	3.	Alfalfa	June July
35	0.22608399E 00	0.70413025E-01	2.	Alfalfa	August September



The regression results clearly indicate the significant effect of three factors:

1. the crop and season factor which is highly significant
2. the temperature factor
3. the radiation factor

The effects of relative humidity and wind were not significant. It is difficult to arrive at a general conclusion regarding these latter two factors since their range of variability in Israel is relatively narrow compared to the temperature and radiation fluctuations.

The regression was calculated from the same data three more times. In two cases one of the climatic factors was omitted, while in the third case two were disregarded. Table 18 presents the regression calculated without the wind factor, and Table 19 without the relative humidity factor. The regression in Table 20 was computed only from radiation and temperature data, and is similar to the original equation of Blaney and Criddle.

Table 18. Regression without Wind.

VAR	COEFF	STD ERR	MEAN	VALUE 'T'
( 1) 1	0.12077677E-02	0.30639186E-03	0.23099981E 03	3.942
( 2) 2	-0.11824173E-03	0.80697911E-04	0.61677587E 03	-1.465
( 3) 4	0.12617149E-02	0.43437556E-03	0.10900923E 03	2.905
( 4) 5		DEPENDENT	0.15638249E 01	
RSQ=	0.112819			
CONST=	0.12202209E 01	STD ERR OF CONST=	0.51985024E-01	VALUE 'T'= 23.473
RESIDUAL VARIANCE=	0.84503362E-02	RESIDUAL ST ERR=	0.91925711E-01	
HYPOTHESIS J=0.	VALUE 'F' ( 283, 34)=	13.693		



Table 19 Regression without Humidity.

VAR	COEFF	STD ERR	MEAN	VALUE 'T'
( 1) 1	0.13729531E-02	0.28752988E-03	0.23099981E 03	4.775
( 2) 3	-0.36994834E-04	0.97741293E-04	0.15352780E 03	-0.378
( 3) 4	0.11894154E-02	0.43566649E-03	0.10900923E 03	2.730
( 4) 5		DEPENDENT	0.15638249E 01	
RSQ=	0.106541			

CONST= 0.11226955E 01    STD ERR OF CONST= 0.80909026E-01    VALUE 'T'= 13.876

RESIDUAL VARIANCE= 0.85101350E-02    RESIDUAL ST ERR= 0.92250393E-01

HYPOTHESIS J=0. VALUE 'F' ( 283, 34)= 13.344

Table 20. Regression with Temperature and Daylight only.

VAR	CCEFF	STD ERR	MEAN	VALUE 'T'
( 1) 1	0.13679763E-02	0.28679551E-03	0.23099981E 03	4.770
( 2) 4	0.12034718E-02	0.43342552E-03	0.10900923E 03	2.777
( 3) 5		DEPENDENT	0.15638249E 01	
RSQ=	0.106089			

CONST= 0.11166331E 01    STD ERR CF CONST= 0.81531409E-01    VALUE 'T'= 13.696

RESIDUAL VARIANCE= 0.84844626E-02    RESIDUAL ST ERR= 0.92111143E-01

HYPOTHESIS J=0. VALUE 'F' ( 284, 34)= 13.541



From the residual value it is seen that the simplest and yet most exact equation is that which does not include the wind factor but does include the relative humidity. The equation is as follows:

$$\text{Log Et} = 0.0012077677T - 0.00011824173H + 0.0012617149S + \text{crop constant}$$

The general crop constant for this equation is 1.2202209, and the deviations from this constant for the different crops and seasons appear in Table 21.

In the event that relative humidity data are unavailable, one can use the following equation for temperature and radiation data alone, without sacrificing much accuracy:

$$\text{Log Et} = 0.0013679763T + 0.0012034718S + \text{crop constant}$$

In this case, the general crop constant is 1.1166331, and the deviations from this constant for the different crops and seasons appear in Table 22.

A further statistical analysis was carried out to test the KM constant for the crop and season. The constant was broken into its two components, and each was tested individually:

- a. one coefficient for a crop for all the seasons (Table 23)
- b. one coefficient for a season for all the crops (Table 24)

The first case can be used when one is interested in the annual average for the crop without considering shorter periods than entire seasons. The second case, in which a seasonal coefficient is considered without specifying the type of crop, is somewhat similar to Thornthwaite's method, and is suitable for making general estimates.



Table 21. Deviations from the average Constant for the different Crops.

J	GROUPS	DEV.	CF	CONST	STD	ERR	GROUP	SIZE	CROP	Season
1	0.40100027E-01			0.41722261E-01			6.		Apples	April May
2	0.10768333E 00			0.27806238E-01			13.		Apples	June July
3	0.23252513E-01			0.32946662E-01			9.		Apples	August September
4	0.10565883E-01			0.30405141E-01			12.		Apples	October November
5	0.17608322E 00			0.43163319E-01			6.		Plums	April May
6	0.87240829E-01			0.23254525E-01			19.		Plums	June July
7	-0.52739898E-02			0.28874262E-01			12.		Plums	August September
8	-0.13783705E 00			0.31929359E-01			11.		Plums	October November
9	-0.95989935E-01			0.25137202E-01			22.		Grapes	April May
10	-0.75496835E-01			0.18372808E-01			32.		Grapes	June July
11	-0.51C31242E-01			0.20757723E-01			27.		Grapes	August September
12	-0.69145972E-01			0.38849327E-01			7.		Grapes	October November
13	0.92545001E-01			0.35264489E-01			10.		Peach	April May
14	0.13861627E 00			0.40720112E-01			6.		Peach	June July
15	C.75177633E-01			0.56678836E-01			3.		Peach	August September
16	-0.24340095E-01			0.36289633E-01			9.		Lemon	April May
17	-0.19588976E-01			0.30478544E-01			11.		Lemon	June July
18	-0.13813542E 00			0.29303284E-01			12.		Lemon	August September
19	-0.18987596E 00			0.98730328E-01			1.		Lemon	October November
20	-0.90001220E-01			0.49893174E-01			4.		Orange	April May
21	-0.37767773E-01			0.44530436E-01			5.		Orange	June July
22	-0.78432512E-01			0.37375131E-01			7.		Orange	August September
23	-0.15399069E 00			0.99545052E-01			1.		Orange	October November
24	-0.58434608E-01			0.42529269E-01			6.		Grapefruit	April May
25	-0.46811347E-01			0.49376342E-01			4.		Grapefruit	June July
26	-0.7868241E-01			0.44417014E-01			5.		Grapefruit	August September
27	-0.51815564E-01			0.50566235E-01			4.		Cotton	October September
28	0.55590697E-01			0.30075884E-01			11.		Cotton	June July
29	0.28727571E-01			0.29450631E-01			12.		Cotton	August September
30	0.18105541E 00			0.31812246E-01			10.		Peanuts	June July
31	0.56149165E-01			0.38506122E-01			7.		Peanuts	August September
32	0.26063926E 00			0.51718485E-01			4.		Alfalfa	April May
33	0.23070187E 00			0.34741279E-01			8.		Alfalfa	June July
34	0.22839763E 00			0.57905607E-01			3.		Alfalfa	May September
35	0.22772185E 00			0.70172474E-01			2.		Alfalfa	October November



Table 22 Deviations from the average Constant for the different Crops.

J GROUPS	DEV.	OF	CCNST	STD	ERR	GROUP	SIZE	Crop	Season
1	0.51414188E-01		0.40937886E-01			6.		Apples	April May
2	0.10471376E 00		0.27688383E-01			13.		Apples	June July
3	0.20307685E-01		0.32830019E-01			9.		Apples	August September
4	0.12856965E-01		0.30327395E-01			12.		Apples	October November
5	0.18520379E 00		0.42657857E-01			6.		Plums	April May
6	0.81549603E-01		0.22891471E-01			19.		Plums	June July
7	-0.97260207E-02		0.28667407E-01			12.		Plums	August September
8	-0.13656935E 00		0.31879519E-01			11.		Plums	October November
9	-0.81993942E-01		0.23228178E-01			22.		Grapes	April May
10	-0.76728702E-01		0.18329307E-01			32.		Grapes	June July
11	-0.61002449E-01		0.195821107E-01			27.		Grapes	August September
12	-0.65120701E-01		0.38697565E-01			7.		Grapes	October November
13	0.10929873E 00		0.333318744E-01			10.		Peach	April May
14	0.14343517E 00		0.40521143E-01			6.		Peach	June July
15	C. 72743814E-01		0.56556983E-01			3.		Peach	August September
16	-0.49877218E-02		0.33750684E-01			9.		Lemon	April May
17	-0.21744782E-01		0.30396938E-01			11.		Lemon	June July
18	-0.14765814E 00		0.28526148E-01			12.		Lemon	August September
19	-0.2CC17042E 00		0.98313161E-01			1.		Lemon	October November
20	-0.84198506E-01		0.49655149E-01			4.		Orange	April May
21	-0.48201739E-01		0.43882268E-01			5.		Orange	June July
22	-0.82378169E-01		0.37215248E-01			7.		Orange	August September
23	-C. 13216362E 00		0.98256940E-01			1.		Orange	October November
24	-0.50133830E-01		0.42092982E-01			6.		Grapefruit	April May
25	-0.55293775E-01		0.48951187E-01			4.		Grapefruit	June July
26	-0.86167733E-01		0.44046964E-01			5.		Grapefruit	August September
27	-0.41170122E-01		0.49962696E-01			4.		Grapefruit	October November
28	0.51055290E-01		0.29867142E-01			11.		Cotton	June July
29	0.19811371E-01		0.28769140E-01			12.		Cotton	August September
30	0.17567619E 00		0.31549536E-01			10.		Plums	June July
31	0.45007472E-01		0.37687777E-01			7.		Plums	August September
32	0.27718681E 00		0.50393911E-01			4.		Alfalfa	April May
33	0.23148248E 00		0.34677733E-01			8.		Alfalfa	June July
34	0.21659442E 00		0.57248984E-01			3.		Alfalfa	August September
35	0.21869844E 00		0.69785254E-01			2.		Alfalfa	October November



Table 23 Regression - Temperature, Humidity & Sunshine for Crop Constants without Seasons.

VAR	COEFF	STD ERR	MEAN	VALUE 'T'
( 1 ) 1	0.11925620E-02	0.20543412E-03	0.23171945E 03	5.805
( 2 ) 2	-0.16001812E-03	0.71229739E-04	0.61869726E 03	-2.247
( 3 ) 4	0.22868213E-02	0.39046403E-03	0.10934882E 03	5.857
( 4 ) 5		DEPENDENT	0.15686963E 01	.
RSQ=	0.254030			

ERROR CONDITION AT 053712 FORTRAN ERROR 14 IGNORED, RETURN TO EXECUTION

CONST= 0.11412981E 01	STD ERR OF CONST= 0.65143612E-01	VALUE 'T'= 17.520
RESIDUAL VARIANCE= 0.10212400E-01	RESIDUAL ST ERR= 0.10105642E 00	
HYPOTHESIS J=0. VALUE 'F' ( 307, 9)= 25.986		

VARIANCE AND COVARIANCE MATRIX OF COEFF.

	1	2	3
1	0.42203179E-07	-0.11307697E-08	-0.27654240E-07
2	-0.11307697E-08	0.50736757E-08	-0.21568972E-08
3	-0.27654240E-07	-0.21568972E-08	0.15246216E-06

J GROUPS	DEV. OF CONST	STD ERR	GROUP SIZE	Crop
1	0.49524295E-01	0.18563744E-01	40.	Apples
2	0.25279421E-01	0.17033817E-01	48.	Plums
3	-0.79275712E-01	0.12519152E-01	88.	Grapes
4	0.92554866E-01	0.27592038E-01	19.	Peach
5	-0.75046223E-01	0.20423922E-01	33.	Lemon
6	-0.73346578E-01	0.28428243E-01	17.	Orange
7	-0.57892323E-01	0.26994690E-01	19.	Grapefruit

8	0.35092168E-01	0.24715109E-01	23.	Cotton
9	0.12063153E 00	0.28776883E-01	17.	Peanuts
10	0.23466033E 00	0.28405418E-01	17.	Alfalfa



Table 24 Regression—Temperature, Humidity &amp; Sunshine for Seasonal Constants without Crops.

VAR	COEFF	STD ERR	MEAN	VALUE • T•
( 1 ) 1	0.11396847E-02	0.40060095E-03	0.23171944E 03	2.845
( 2 ) 2	-0.12238229E-03	0.10242731E-03	0.61869729E 03	-1.195
( 3 ) 4	0.87295394E-03	0.58694630E-03	0.10934881E 03	1.487
( 4 ) 5		DEPENDENT	0.15686963E 01	
RSQ =	0.048614			

CONST = 0.12848703E 01 STD ERR CF CONST = 0.87961201E-01 VALUE • T• = 14.607

RESIDUAL VARIANCE = 0.16693439E-01 RESIDUAL ST ERR = 0.12920309E 00

HYPOTHESIS J=0. VALUE 'F' ( 313, 3 ) = 6.098

## VARIANCE AND COVARIANCE MATRIX OF COEFF.

1	2	3
1 0.16048113E-06	0.12593632E-07	-0.29120366E-07
2 0.12593632E-07	0.10491353E-07	-0.41646887E-08
3 -0.29120366E-07	-0.41646887E-08	0.34450597E-06

J GROUPS	DEV. OF CONST	STD ERR	GROUP SIZE	Season
1	-0.50173154E-02	0.24963649E-01	67.	April May
2	0.44283525E-01	0.14490529E-01	119.	June July
3	-0.24881230E-01	0.16434002E-01	97.	August September
4	-0.66308618E-01	0.26655250E-01	38.	October November



#### Comparison of Equations for Estimating Evapotranspiration

In order to compare the equation obtained with other methods and equations, data from 10 crops were used. The actual monthly evapotranspiration for each crop was compared to values calculated from the equation henceforth called "the Rehovot Equation" and also to values derived with the Thornthwaite and Blaney-Criddle equations (see Tables 25-34). The crop coefficients for the Blaney-Criddle equation were obtained from two sources:

- a. coefficients determined by Blaney during his visit to Israel in 1961, and
- b. data published by Blaney and Criddle in California for similar climatic regions.

The distribution of deviations of the values calculated with the three equations from the measured values is shown in Figure 25. The deviations are expressed as percentages of the measured evapotranspiration values, and are divided into 5 size groups: 1.  $\pm 10\%$ ; 2.  $+10\%$  to  $+30\%$ ; 2.  $+30\%$ ; 4.  $-10\%$  to  $-30\%$ ; 5.  $\pm>30\%$ .



Table 25 Computed & measured monthly evapotranspiration in mm.  
A P P L E S

Month	April - May	June - July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.		Avarage	Seasonal	Coeff. 0.65
Rehovot Coeff.	1.26759470	1.33548391	1.250205584	1.23695946

R E S U L T S

Rehovot Formula	Thornthwaite Formula	Blaney Criddle Formula	Actual Measurement
114.7	88.5	107.3	121.0
147.0	129.9	118.7	153.0
158.1	151.2	125.2	158.0
133.3	160.7	123.2	149.0
120.0	126.7	106.3	125.0
108.5	97.0	95.2	121.0
97.2	42.5	81.0	69.0
127.1	136.8	117.1	150.0
117.0	114.0	101.0	121.0
69.0	97.0	91.9	195.0
102.0	64.8	92.2	63.0
117.8	92.0	107.6	42.0
150.0	129.9	118.7	153.0
158.0	136.8	122.9	169.0
127.0	136.8	118.0	167.5
114.0	114.3	103.1	120.0
102.3	82.3	90.4	99.5
87.0	47.5	72.0	88.5
96.0	61.6	90.0	117.0
141.0	131.0	120.0	159.0
155.0	145.2	124.0	149.0
127.1	148.3	118.0	109.0
117.0	117.4	117.0	92.0
99.2	82.3	90.0	75.0
93.0	58.0	80.0	84.0



Table 26 Computed & measured monthly evapotranspiration in mm.  
PLUMS

Month	April - May	June ~ July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.		Average	Seasonal	Coeff. o. 65
Rehovot Coeff.	1.40440174	1.31495399	1.22218311	1.08854787

### RESULTS

Rehovot Formula	Thorntewaite Formula	Blaney Criddle Formula	Actual Measurement
138.0	129.9	118.7	190.0
151.9	151.2	125.2	183.0
124.0	160.7	123.2	125.0
114.0	126.7	106.3	129.0
77.5	97.0	95.2	95.5
69	47.5	78.0	72.0
117.8	136.0	117.1	90.0
108.0	114.0	101.0	87.0
74.4	82.0	91.9	62.0
138.0	64.8	92.2	145.0
164.3	92.0	107.6	169.0
144.0	129.8	118.7	159.0
151.9	139.8	122.9	130.0
117.8	136.8	118.0	124.0
108.0	114.3	103.1	86.5
71.3	82.3	90.4	66.5
62.0	47.5	80.0	62.0
132.0	58.3	90.0	129.0
135.0	121.4	117.0	193.0
145.7	141.6	124.0	100.0
117.8	141.4	118.0	112.0
96.0	114.6	102.0	105.0
77.5	88.2	93.0	68.0
63.0	60.7	82.0	63.0
132.0	61.6	90.0	141.0
155.0	89.2	108.0	108.0
135.0	131.0	120.0	150.0
145.0	145.2	124.0	175.0
117.8	148.3	118.0	153.0
108.0	117.4	117.0	90.0
71.3	82.3	90.0	75.0
63.0	58.0	80.0	84.0



Table 27 Computed & measured monthly evapotranspiration in mm.  
P E A C H

Month	April - May	June - July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.		Avargae	Seasonal	Coeff. o. 65
Rehovot Coeff.	1.3194994	1.36464397	1.30120554	
R E S U L T S				
Rehovot Formula	Thornthwaite Formula	Blaney Criddle Formula	Actual Measurement	
138.8	127.4	122.0	167.0	
142.0	143.6	120.0	167.0	
111.3	68.0	94.0	102.0	
131.1	85.0	114.0	118.0	
162.6	126.4	119.0	148.0	
170.5	144.0	126.0	189.0	
145.7	143.6	120.0	120.4	
119.4	71.3	97.0	164.0	
158.7	95.6	116.0	178.0	
170.0	136.9	121.0	172.0	
177.0	158.4	130.0	174.0	

Table 28 Computed & measured monthly evapotranspiration in mm.  
L E M O N

Month	April - May	June - July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.	0.4	0.5	0.55 0.6	0.5 0.4
Rehovot Coeff.	1.20275194	1.20687893	1.08775362	
R E S U L T S				
Rehovot Formula	Thornthwaite Formula	Blaney Criddle Formula	Actual Measurement	
106.0	127.4	72.5	102.3	
112.0	157.9	96.5	132.0	
120.5	169.2	100.0	117.8	
87.0	143.7	100.6	117.8	
79.0	108.5	103.5	105.0	
113.0	126.4	91.1	141.0	
117.0	144.0	93.8	105.4	
89.0	143.7	100.8	63.2	
76.5	111.2	103.5	111.0	
121.0	95.6	62.0	90.0	
119.0	136.9	93.4	120.9	
123.0	158.4	96.0	86.8	
89.0	143.6	100.8	72.0	
79.5	114.3	105.0	75.0	



Table 29 Computed & measured monthly evapotranspiration in mm.  
ORANGE

Month	April - May	June - July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.	0.4	0.55	0.55	0.5
Rehovot Coeff.	1.13983640	1.13983640	1.14987975	1.07302382
RESULTS				
Rehovot Formula	Thorntwaite Formula	Blaney Criddle Formula	Actual Measurement	
72.5	58.3	55.4	60.0	
84.0	85.7	64.4	89.0	
102.0	121.4	96.9	111.0	
110.5	141.6	102.9	124.0	
100.0	141.5	100.9	120.9	
92.0	114.3	78.3	63.0	
71.3	61.7	56.1	78.0	
110.0	145.2	103.9	96.1	
103.0	148.3	101.3	114.7	
92.0	117.4	79.2	102.0	

Table 30 Computed & measured monthly evapotranspiration in mm.

Month	April - May	June - July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.	0.4	0.55	0.55	0.5
Rehovot Coeff.	1.17130535	1.18177989	1.14955121	1.7637739
RESULTS				
Rehovot Formula	Thorntwaite Formula	Blaney Criddle Formula	Actual Measurement	
90.0	85.7	64.4	93.0	
95.0	121.4	96.9	123.0	
108.5	141.6	102.9	127.7	
100.0	141.5	100.9	108.5	
91.5	114.3	78.3	84.0	
94.5	88.2	70.5	77.5	
77.5	61.6	56.1	75.0	
90.5	89.2	65.9	83.7	
98.5	131.0	99.5	96.0	
108.0	145.2	103.9	99.2	
100.0	148.3	101.3	132.5	
92.0	117.4	79.2	66.0	
87.0	82.3	69.3	111.6	



Table 31 Computed & measured monthly evapotranspiration in mm.

C O T T O N

Month	April - May		June - July		Aug - Sep		Oct - Nov
Blaney Criddle Coeff.	0.4.	0.55	0.7	0.8	0.8	0.7	0.6
Rehovot Coeff.			1.28280245		1.25520178		

R E S U L T S

Rehovot Formula	Thornthwaite Formula	Blaney Criddle Formula	Actual Measurement
129.5	129.9	127.9	132.0
140.0	151.2	153.9	158.0
135.0	160.7	151.4	142.6
123.0	126.7	113.9	138.0
127.0	114.3	143.6	158.1
134.0	129.9	127.9	150.0
141.0	136.0	151.0	179.8
128.5	136.8	145.0	164.3
115.0	114.3	110.5	87.0



Table 32 Computed & measured monthly evapotranspiration in mm.

G R A P E S .

Month	April - May	June - July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.		Seasonal Coeff.: 0.65		
Rehovot Coeff.	1.13168762	1.15139084	1.17546484	1.15696582

R E S U L T S

Rehovot Formula	Thornthwaite Formula	Blaney Criddle Formula	Actual Measurement
84.9	88.5	107.3	108.5
95.7	129.9	118.7	111.0
104.1	151.2	125.2	134.0
112.5	160.7	123.2	136.5
102.0	126.7	106.3	127.0
89.5	97.0	95.2	89.5
106.0	160.7	117.1	130.0
97.5	126.7	101.0	106.5
73.8	64.8	92.2	86.2
87.4	92.0	107.6	91.0
98.7	129.8	118.7	114.0
104.1	136.8	122.9	104.0
103.5	136.8	118.0	127.5
96.9	114.3	103.1	96.0
83.7	82.3	90.4	112.0
71.7	47.5	78.1	72.0
71.4	58.3	90.0	54.0
82.1	85.7	105.0	69.0
93.0	121.4	117.0	86.0
101.0	141.6	124.0	64.0
106.0	141.5	118.0	59.0
97.2	114.3	102.0	54.0
90.2	88.2	93.0	69.0
70.2	61.6	90.0	70.5
82.0	89.2	108.0	68.0
92.1	131.0	120.0	88.5
100.7	145.2	124.0	140.0
100.3	148.3	118.0	124.0
97.8	117.4	117.0	118.0
82.8	82.3	90.0	71.5

Continued on next page



Table 32 (Continued)

Rehovot Formula	Thornthwiate Formula	Blaney Criddle Formula	Actual Measurement
74.4	57.1	81.0	81.0
87.0	127.4	122.0	96.0
102.3	157.9	104.0	90.0
105.4	169.2	138.0	93.0
106.3	143.6	120.0	93.0
96.6	108.1	108.0	79.5
72.0	68.0	94.0	77.0
85.1	84.9	114.0	118.0
99.6	126.4	119.0	100.0
103.2	144.0	126.0	111.0
108.8	143.6	120.0	121.0
77.4	72.3	97.0	81.0
102.9	95.6	116.0	124.0
104.1	136.9	121.0	156.0
108.5	158.4	130.0	117.0
108.5	143.6	120.0	130.0
97.2	114.3	108.0	90.5



Table 33 Computed & measured monthly evapotranspiration in mm.  
A L F A L F A

Month	April - May	June - July	Aug - Sep	Oct - Nov
Blaney Criddle Coeff.	0.7 . . 0.75	0.8 . 0.95	0.95 0,8	0.75
Rehovot Coeff.	1. 48823899	1. 45743416	1. 4575291	

### R E S U L T S

Rehovot Formula	Thornthwaite Formula	Blaney Criddle Formula	Actual Measurement
183	97.2	108	168
202.5	127.4	141	218
211	157.9	156	213
212	169.2	189	217
197	143.6	170	237
164	68.0	97	159
194	85.0	118	174
201	126.4	149	198
203.5	143.6	170	168
178.5	111.2	130	162
210	144	176	186

Table 34 Computed & measured monthly evapotranspiration in mm.  
P E A N T U S

Month	April - May	June - July	Aug - Sep	Octo - Nov
Blaney Criddle Coeff.	-	Seasonal Coeff. 0.7		
Rehovot Coeff.		1. 41113993	1. 28206852	

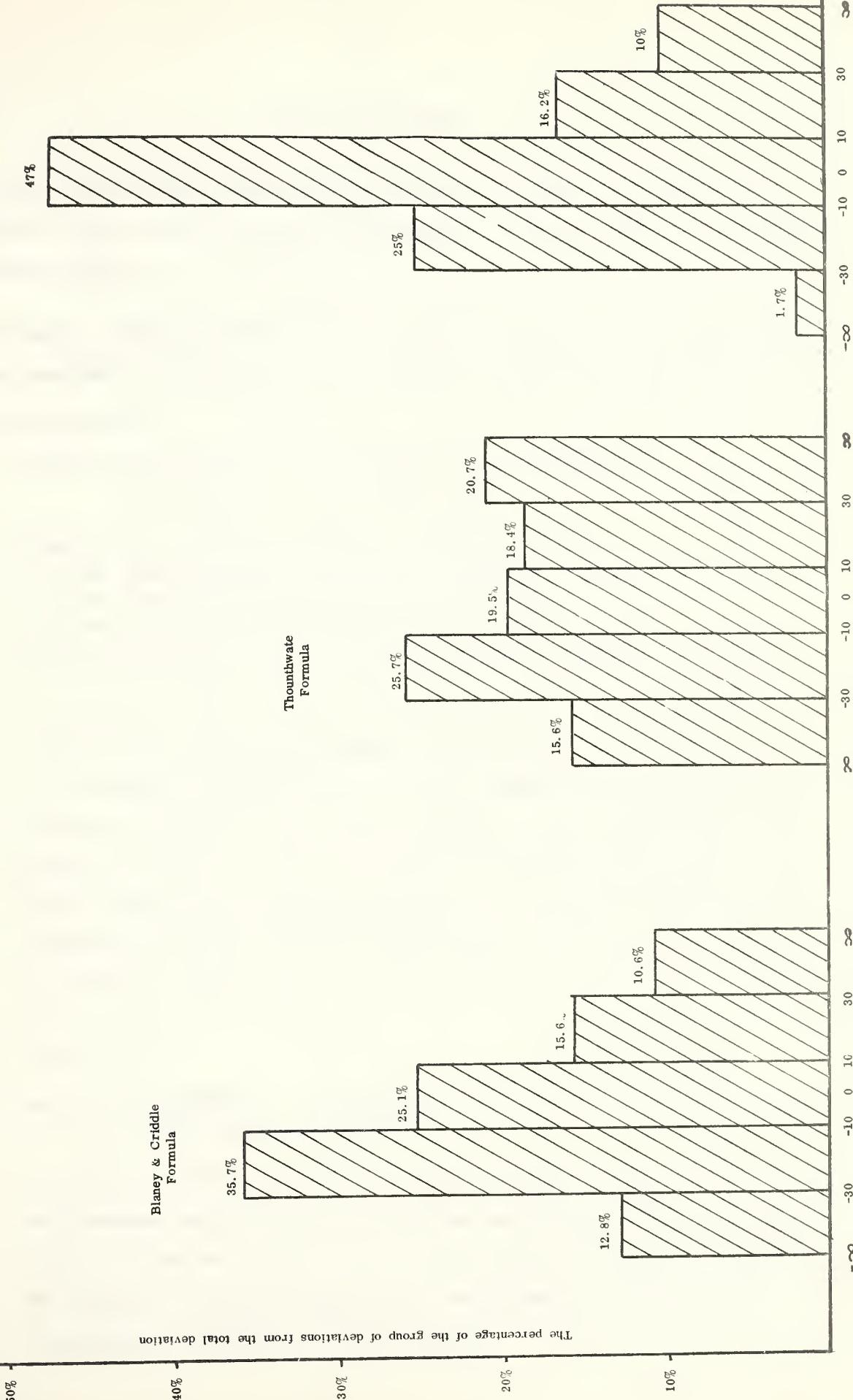
### R E S U L T S

Rehovot Formula	Thornthwaite Formula	Blaney Criddle Formula	Actual Measurement
193	169.2	145	180
135	143.6	143	128
181.5	126.3	133	159
190.0	144	140	181
138.5	143.6	143	135
190	136.9	143	189
197	158.4	134	201



Table 25. Distribution of deviation in percentage of the computed values from the measured values

Rehovot Formula



The percentage of the deviation from the actual measurements.



## CONCLUSIONS

This Final Report, summarizes in effect, five years of strenuous work, the results of which appear in these three volumes. It is our desire to emphasize the following points:

1. The Rehovot Formula (or Formulae) is presented in six versions, each having advantages and disadvantages, the comments to which will appear hereunder:

### 1.1 Version No. 1.

$$\log Et = 0.012123132T - 0.001188055H - 0.0000394669W + \\ 0.01249969S + (0.12271823 \pm KM)$$

Where T is in Degrees Celcius on a daily average.

H is the daily average of the Relative Humidity in percent.

W is the movement of the Wind in k'm per day.

S is the actual daily Sunshine hours on an average basis.

KM is the deviation of the specific Crop from the general Coefficient.

The values of KM in this equation appear in Table 17 on page 42.

This equation is the most general form presented, in that it embraces all the climatic variables that have been examined during the research.

It has been pointed out in the text, that three - the Temperature, the Sunshine & the Crop - were significant, while the remaining two - the Relative Humidity was found less significant while the Wind was actually insignificant (causes for the less significance and the insignificance will be given later on).

### 1.2 Version No. 2

$$\log Et = 0.012077677T - 0.0011824173H + \\ + 0.012617149S + (0.12202209 \pm KM)$$

The values of KM in this equation appear in Table 21 page 46.

This equation might seem less exact than version No. 1 due to the fact that it has one less variable (the Wind), however it may be assumed that the influence of Wind is insignificant, and therefore in practice, this formula may be found to be just as exact.



1.3 Version No. 3.

$$\log Et = 0.013679763T + 0.012034718S + (0.11166331 \pm KM)$$

The values of KM in this equation appear in Table 22 page 47.

This equation brings into consideration the three significant variables only (the Temperature, Sunshine & Crop). Generally speaking this equation bears resemblance to the Blaney & Criddle equation with Crop Coefficients of Seasonal nature.

This equation is less exact, and should be used only when Relative Humidity Data is not available.

1.4 Version No. 4.

$$\log Et = 0.013729531T - 0.000036994834W + 0.011894154S + \\ + (0.11226955 \pm KM)$$

This is the least practical equation, in that the Wind factor is insignificant, making the equation of a doubtful use.

1.5 Version No. 5.

$$\log Et = 0.01192562T - 0.0016001812H + 0.022868213S + \\ + (0.11412981 \pm KM)$$

The values of KM in this equation appear in Table 23 page 48.

This equation is similar to version No. 2 with the exception that KM in this case has yearly values and not seasonal values.

This equation could be best used, when the inter-seasonal changes are rather slight or when the seasonal variations are little known.

1.6 Version No. 6.

$$\log Et = 0.011396847T - 0.0012238229H + 0.0087295394S + \\ + (0.12848703 \pm KM)$$

The values of KM in this equation appear in Table 24 page 49.

This equation is similar to version No. 5 with the exception that the Crop Coefficient is Universal to all the Crops, and there are four coefficients on a seasonal basis. The four seasons represent diverse periods of physiological plantal activities. This equation bears some resemblance to the Thornthwaite's approach.



2. The basis of our studies, indeed, the derivation of the Rehovot Formulae, are a product of a tremendous number of observations (the observations appearing in our Volume II Information & Data are only the selected portion of the actual takings), taken in controlled commercial fields. In spite of the fact that we had the utmost cooperation from our selected commercial growers, it should be admitted that we often faced difficulties that arrise from such a Union. Having gone through a highly strenuous period, we are still convinced, that for the sake of authenticity, Et equations should be based on commercial field findings. The lack of significance in our Humidity and Wind variables, is no doubt, due to the samll climatic variations in Israel of these two factors and due to the insufficient number of data of variable nature that we possessed.

This study may enlighten future students on Et to select greater climatic diversity in greatly dispersed areas, and plan a greater plan of operation for periods of eight to ten years.

Should the selection be challenged whether to operate in "commercial" fields as against the operation on "experimental plots", we definitely prefer the "commercial" approach.

3. The Data appearing in Volume II INFORMATION AND DATA may be of great help to students carrying future studies on Evapotranspiration. This material has been very carefully selected and compiled.
4. Great effort has been placed to carry out a comprehensive review of the relevtent material, this in itself may be of use to Evapotranspiration students, Volume III LITERATURE REVIEW AND BIBLIOGRAPHY may be of help.



#### ACKNOWLEDGEMENTS

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6. The Director and Staff of the Israel Meteorological Service for help and guidance on Agro-Meteorological matters.
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LIST OF PUBLICATIONS

1. D. Goldberg, B. Gornat, D. Sadan - The Use of U.S.W.B. Class A, Evaporation Pan Data for the Determination of Water Consumption and Irrigation Schedule of Ground Nuts Growing in Sandy Soil. Bulletin 498 of the National and University Publications. 1965.
2. D. Goldberg, M. Shmueli, B. Gornat - Field Experiments on Consumptive Water Use and Irrigation at Yotvata (1964/5). Bulletin 508 of the National and University Publications. 1966.
3. D. Glodberg, B. Gornat, D. Sadan - A study of Irrigation Practices of Groundnuts in the Bsor Area with the aid of U.S.W.B. Class "A" Pan. The Ktavim Journal Volume 16, No. 2, 1966.
4. D. Goldberg, B. Gornat, D. Sadan - The Relation Between Water Consumption of Peanuts and Class "A" Pan Evaporation during the Growing Season. Soil Science, published in October 1967 (not yet received).
5. D. Goldberg, B. Gornat, D. Sadan - Estimating the Consumptive Water Use of Sugar Beets During Autumn and Winter. Scientific Publications, Pamphlet No. 123 The National and University Publications. 1967



VOLUME II. GENERAL INFORMATION AND DATA

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1.	General description and maps	1
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4.	Crop and irrigation data 1963	27
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## GENERAL INFORMATION AND DATA

General description of our experiments: To those who know little of our farm and our farming practices, I wish to state that practically all of our work is performed in communal settlements (Kibbutzim) which are based on large estates of over 1000 acres each (completely irrigated), owned and worked collectively by their own member farmers. The map of Israel (attached) and the maps of the individual settlements (also attached), indicate their location. The only exception is Kefar Hayarok, which is also run collectively, but it is an Agricultural Secondary school.

Some explanations to the attached map of the country: Jerusalem is the Capital, while Tel-Aviv is the largest city (population about 300,000) and with its neighbouring sister cities the population is about 700,000. Rehovot is the seat of the faculty of agriculture. Kefar Hayarok is a Secondary agricultural school and it possesses an agricultural area of 4000 dunams. We have good facilities there which give good promise to become our central Laboratory. Saad is communal settlement of a religious group. They normally grow the following: 10,000 dunams of non-irrigated winter grain, 200 dunams of irrigated alfalfa and pasture, 1200 dunams of industrial crops, 1000 dunams of vegetables, 1000 dunams of assorted fruit trees. Not in all crops we can enter, this depends upon prior negotiations. Nir Itzhak is deep in the Southwest Negev, where the rainfall is very small (see our climatic map attached). They normally grow the following: 270 dunams of Citrus Orchard (Oranges & Lemons), 230 dunams of assorted plantations, 1620 dunams of industrial crops (including Ground nuts and Potatoes), 65 dunams of alfalfa. Several thousand dunams of winter grain with supplemental irrigation.

Each experimental site has three distinct elements: 1. An agro-Meteorological station. 2. A complete field moisture study laboratory. 3. The various commercial fields in which irrigation is conducted under our instructions and the local moisture study sites (random taken) where soil samples are taken to our field laboratory.



We study the following crops in the following locations:

In Saad

100 dunams of cotton Azala 442.  
45 dunams apples.  
56 dunams plums.  
45 dunams vineyard.

In Nir Itzhak, Out of a total area of 400 dunams of ground nut growing we carry observation on a plot of 40 dunams.

65 dunams of alfalfa.  
36 dunams of lemons.  
23 dunams of peaches.  
58 dunams of vineyard.

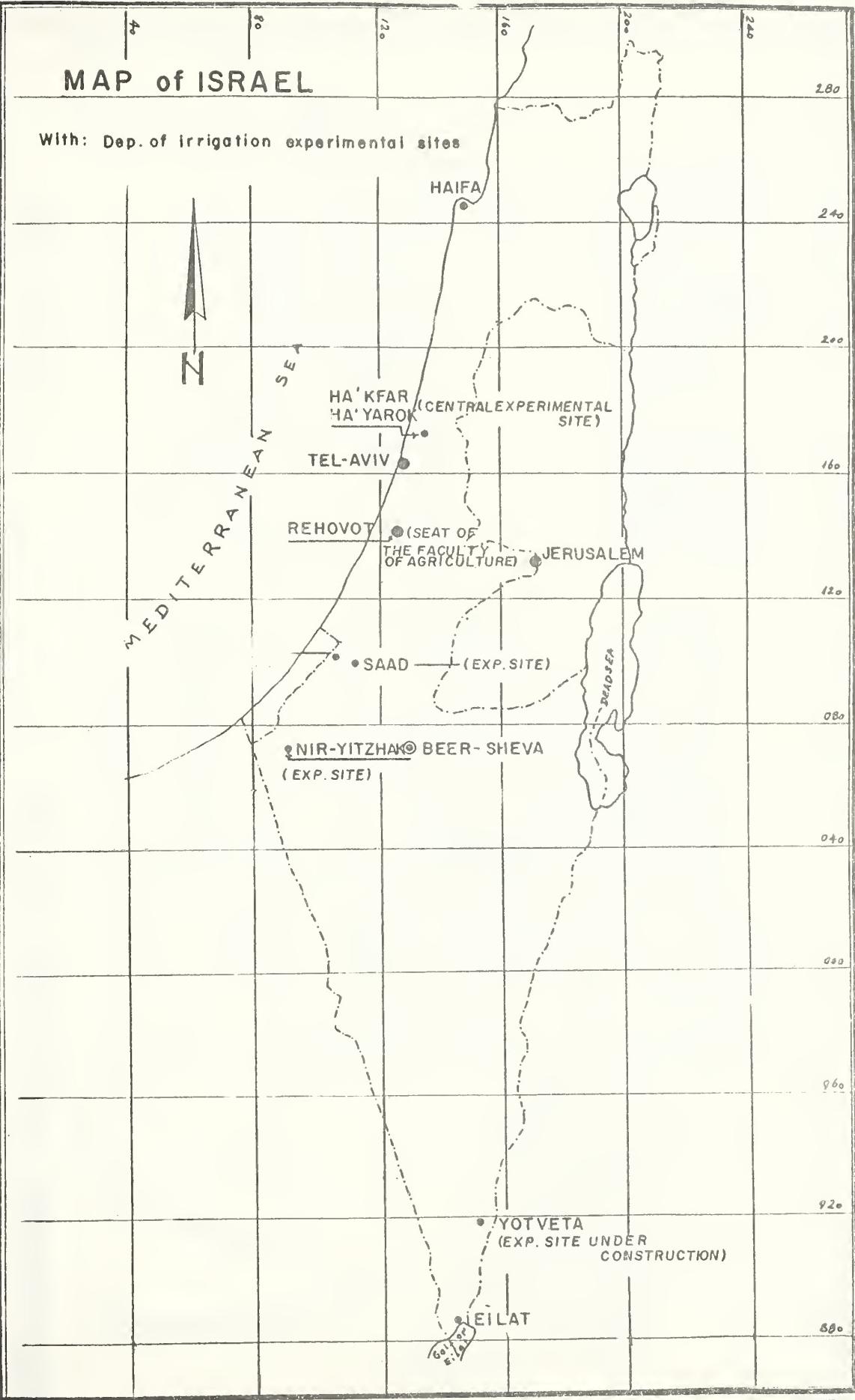
In Kefar Hayarok

12 dunams of apples.  
25 dunams of oranges.  
12 dunams of grapefruit.  
5 dunams of plums.  
5 dunams of peaches.  
21 dunams of vineyard.



# MAP of ISRAEL

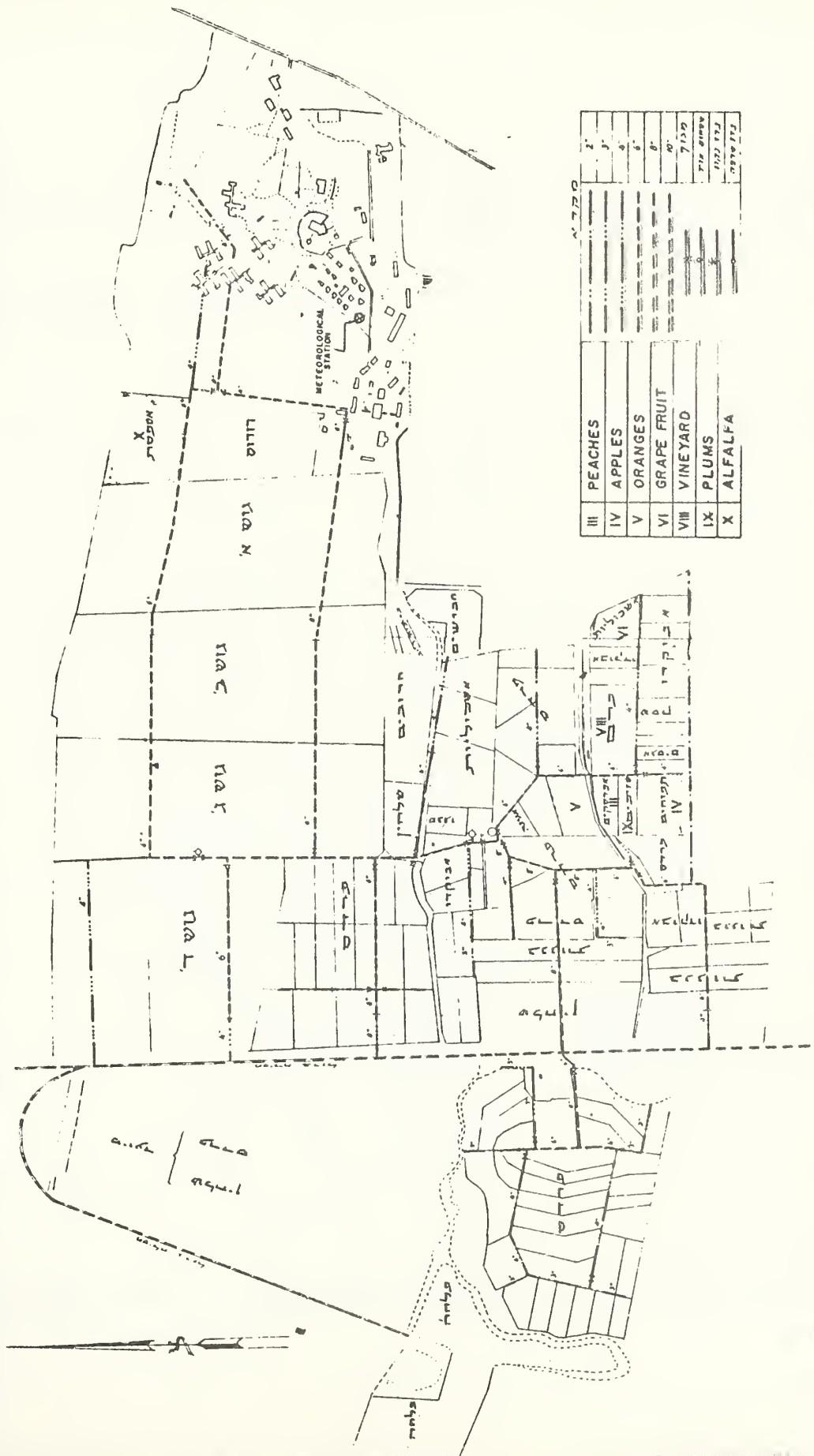
With: Dep. of Irrigation experimental sites





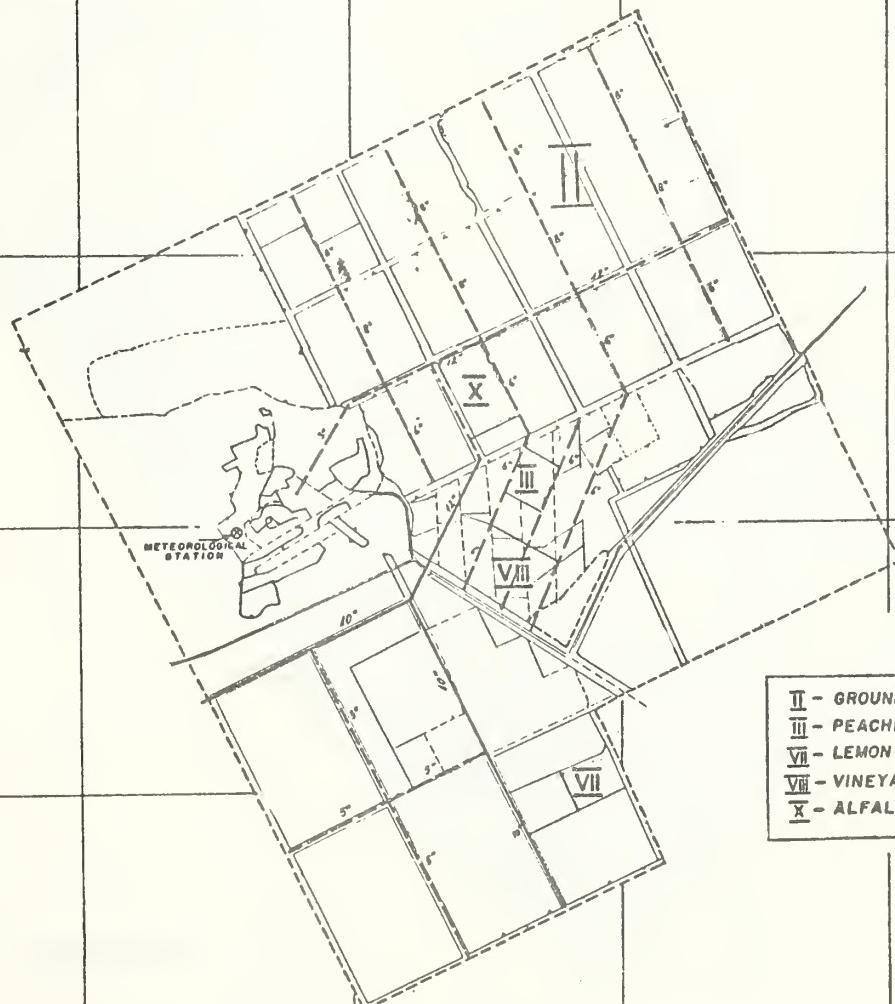
## KEFAR HAYAROK, AGRICULTURAL SCHOOL

כט - ל' ר' ז





NIR ITZHAK, SETTLEMENT



- |                  |
|------------------|
| II - GROUND NUTS |
| III - PEACHES    |
| VII - LEMON      |
| VIII - VINEYARD  |
| X - ALFALFA      |



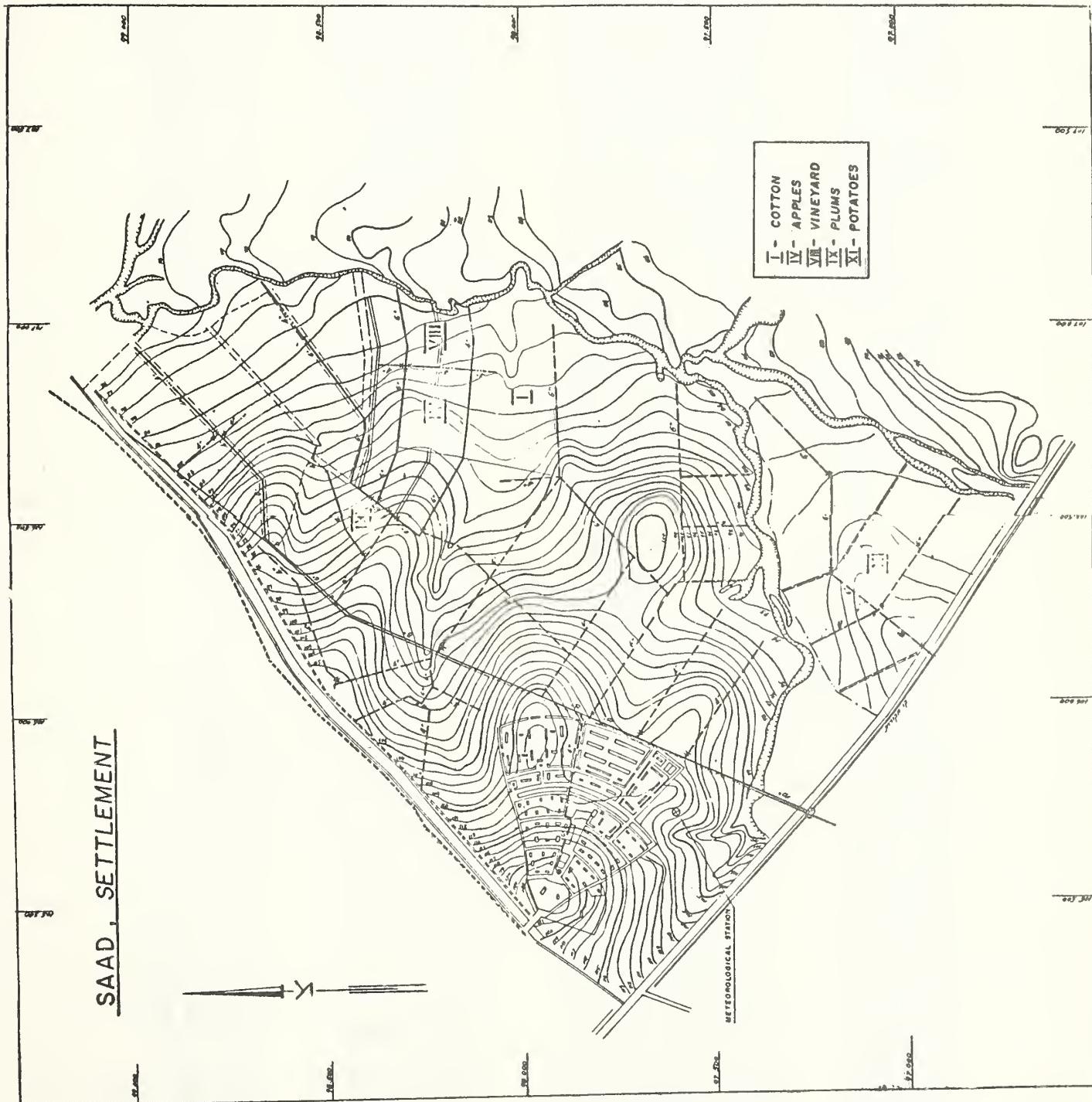




TABLE IV  
of Temperature ( $^{\circ}\text{C}$ ) הצעה שטחן טרמומטרים

### Average Daily Range of Temperature ( $^{\circ}\text{C}$ )

Month	Year	Station												Month											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII

TABLE III  
Average Daily Temperature ( $^{\circ}\text{C}$ )  
during the Month of January

הטמפרטורה הימית ממוצעת (°C) נעה בין 10 ו-20.

A. COASTAL REGION										B. HILLS & PLATEAUS									
9.5	9.0	10.7	10.9	9.2	8.3	8.2	8.8	10.1	10.6	10.0	9.5	8.5	Acre	Haifa, Mt. Carmel	19.9	15.4	20.0	22.8	24.9
6.8	5.9	6.6	7.1	6.2	6.2	6.4	7.1	8.3	7.6	7.3	7.0	6.0	Haifa, Mt. Carmel	Tel Shalom	18.8	13.8	19.4	22.2	23.9
9.9	8.0	10.1	11.1	9.8	9.6	9.8	10.5	11.6	11.1	9.6	9.3	8.6	Tel Shalom	Tel Shalem	19.9	15.1	20.0	23.2	23.9
9.0	8.9	10.1	9.9	8.7	8.2	7.8	8.4	9.2	9.4	9.2	8.9	8.6	Natanya	Tzfat, Givatayim	19.7	15.0	19.6	22.8	25.0
9.6	9.8	11.0	10.9	9.7	8.7	8.6	9.2	9.6	9.8	9.3	9.4	9.0	Tel Aviv, Shore	Tel Aviv, Givatayim	19.1	14.7	18.7	21.6	23.4
9.0	9.4	10.6	11.0	10.0	9.2	9.2	9.6	10.4	10.5	10.1	9.8	9.7	Tel Aviv, Hakirya	Lod, Airport	20.0	15.3	19.1	22.9	24.7
2.5	1.0	3.0	3.5	1.9	1.8	1.2	1.4	14.8	12.2	11.8	10.7	9.5	Gaza	Gaza	19.5	14.6	19.0	22.6	24.6
0.4	0.4	1.0	1.5	1.4	1.5	1.5	1.6	10.8	11.0	10.5	10.3	9.9	Gaza	Gaza	20.1	15.4	19.8	22.9	25.7

B. HILL REGION	C. JORDAN RIFT
7.1 6.2 5.4 Mt. Keren'an	16.1 9.3 11
9.8 9.6 8.8 Tabor, Agr. School	20.5 14.3 11
3.4 12.8 11.7 Ramat David, Aerod.	19.5 13.6 11
7.7 10.0 9.0 'Afula, Hospital	20.6 14.6 21
11.3 10.5 10.0 Mishmar ha'Emeq	19.8 13.6 14
2.2 11.3 10.2 Heftibah, Gilboa'	21.9 15.4 2
2.9 11.7 10.4 Beit Shean	21.7 15.1 2
7.7 9.7 9.1 Jenin	20.4 14.0 14
3.4 7.4 6.6 Ramallah	16.4 10.5 13
0.2 8.0 7.3 Jerusalem, Palace Hotel	17.1 11.0 20
1.1 8.2 7.4 Beit Jimal	20.2 14.9 20
2.0 12.1 10.8 Beer Sheba	19.5 13.5 14

GORDAN RIFT



TABLE VI פִּילְבָּס

Average Monthly Minimum Temperature (°C) תרמונומטרית ממינימלית חודשית

TABLE V פִּילְבָּס

Average Monthly Maximum Temperature (°C) תרמונומטרית ממינימלית חודשית

Month	Station ח' י ד ש												Month	Station ח' י נ ה ג נ ה נ											
	XII	XI	X	VIII	VII	VI	V	IV	III	II	I	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I		
5.4	8.9	13.0	16.5	19.4	18.3	14.8	10.4	6.9	4.8	4.5	4.1	Acre	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	Haifa, Carmel Ave.	
7.0	10.6	16.4	19.9	22.2	20.8	18.1	14.0	9.7	7.2	6.8	6.4	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	Tiberias, Qir. Shemuel	
7.0	10.6	15.2	18.8	20.8	19.7	16.7	13.1	8.6	6.0	4.8	3.8	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	Deganya A	
6.7	10.5	14.0	17.4	19.2	17.8	15.1	11.4	7.3	5.3	4.0	4.7	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	Jericho	
6.8	9.7	13.8	17.6	19.8	19.0	15.6	11.6	8.0	5.6	5.0	4.5	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	Natanya	
4.9	7.7	11.3	15.3	17.9	17.1	13.7	10.0	6.6	4.2	3.6	3.0	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	Tel Aviv, Shore	
3.6	6.5	10.6	14.9	16.6	15.9	12.6	8.1	4.4	2.6	2.5	1.7	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	Lod, Airport	
5.4	9.3	13.8	16.7	18.7	17.8	15.0	11.3	7.4	5.1	4.7	4.3	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	Gaza	

## A. COASTAL REGION ח' י ג ה נ ה נ

Month	XII	XI	X	VIII	VII	VI	V	IV	III	II	I	Station	Month	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I
5.4	8.9	13.0	16.5	19.4	18.3	14.8	10.4	6.9	4.8	4.5	4.1	Acre	5.4	23.2	31.2	35.7	33.0	32.3	32.0	33.6	36.2	34.1	29.4	24.7	22.3
7.0	10.6	16.4	19.9	22.2	20.8	18.1	14.0	9.7	7.2	6.8	6.4	Haifa, Carmel Ave.	5.4	25.2	32.0	34.8	34.2	33.9	33.4	35.3	38.4	35.2	30.7	24.9	22.7
7.0	10.6	15.2	18.8	20.8	19.7	16.7	13.1	8.6	6.0	4.8	3.8	Haifa, Mt. Carmel	5.4	22.6	29.4	33.1	31.5	30.5	30.8	32.8	34.3	31.7	26.0	22.3	19.5
6.7	10.5	14.0	17.4	19.2	17.8	15.1	11.4	7.3	5.3	4.0	4.7	Tel Shalom	5.4	23.7	31.6	36.1	34.5	33.5	33.7	36.5	35.9	34.1	29.8	25.2	22.3
6.8	9.7	13.8	17.6	19.8	19.0	15.6	11.6	8.0	5.6	5.0	4.5	Natanya	5.4	25.7	31.2	34.8	33.2	31.9	31.2	34.7	32.2	30.0	25.6	23.4	21.1
4.9	7.7	11.3	15.3	17.9	17.1	13.7	10.0	6.6	4.2	3.6	3.0	Tel Aviv, Shore	5.4	23.5	29.8	33.3	32.0	31.8	31.2	31.4	32.9	32.4	30.3	25.1	23.4
3.6	6.5	10.6	14.9	16.6	15.9	12.6	8.1	4.4	2.6	2.5	1.7	Lod, Airport	5.4	27.1	32.4	36.0	35.3	35.5	35.3	37.3	38.4	34.6	30.5	26.9	24.4
5.4	9.3	13.8	16.7	18.7	17.8	15.0	11.3	7.4	5.1	4.7	4.3	Gaza	5.4	26.8	31.4	34.4	33.8	33.5	36.1	38.6	36.0	32.2	27.1	24.1	21.1

## B. HILL REGION ח' י ג ה ה ר י ב

Month	XII	XI	X	VIII	VII	VI	V	IV	III	II	I	Station	Month	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I	
2.0	5.7	10.2	13.2	14.6	14.0	11.4	8.0	3.5	1.0	-0.1	-0.7	Mt. Kedem	5.4	12.0	23.2	31.1	33.1	31.1	31.1	34.3	32.7	27.6	21.7	17.7	15.0	
4.5	8.3	12.9	16.8	18.8	17.8	14.7	10.5	6.4	3.4	3.2	2.0	Tabor, Agr. School	5.4	24.6	31.7	37.6	33.0	38.3	39.8	38.9	35.0	28.9	24.7	21.3	20.0	
1.3	3.7	8.9	14.6	17.1	15.8	12.8	7.2	3.2	0.0	-0.9	-0.6	Ramat David, Aerod.	5.4	21.0	22.4	36.4	36.7	37.0	37.4	38.3	37.4	33.8	28.6	24.4	21.6	20.0
2.8	6.3	10.3	15.6	18.7	17.6	14.1	9.5	5.4	2.6	1.6	1.2	Mishmar ha'Emeq	5.4	21.2	31.6	36.7	36.7	36.1	36.7	38.1	37.2	34.2	28.7	24.5	21.4	20.0
5.1	9.1	13.4	17.7	20.4	19.5	16.1	11.4	6.4	3.0	2.3	1.9	Hetsibah, Gilboa	5.4	23.7	33.1	39.3	39.5	40.0	41.3	40.4	36.4	30.2	25.4	22.6	20.0	
3.6	8.4	12.8	16.1	18.1	18.7	15.2	11.2	5.3	3.6	3.6	2.3	Deit Shean	5.4	23.2	31.6	39.7	40.2	40.4	41.3	37.8	31.1	25.8	23.3	20.0	20.0	
4.4	8.4	13.6	17.4	19.6	18.5	15.6	11.4	7.3	4.9	4.2	3.3	Jenin	5.4	23.8	31.9	37.4	37.7	38.1	38.3	39.4	39.8	35.9	29.3	23.6	21.5	20.0
3.3	7.2	11.3	14.5	15.8	14.9	12.4	6.4	3.0	1.4	1.0	0.0	Jerusalem, Palace Hotel ענבל מלון מלך דוד	5.4	21.3	27.2	33.4	34.3	34.3	33.9	35.0	34.0	30.5	25.2	21.8	18.5	20.0
6.7	10.5	14.5	17.6	19.0	18.9	15.6	11.9	8.0	5.5	4.7	4.6	Bet Hmam	5.4	25.3	31.6	35.9	35.6	36.4	36.6	33.2	33.0	33.9	29.4	25.6	23.4	20.0
3.2	6.4	9.9	13.0	15.1	14.8	12.3	9.0	4.6	2.5	2.1	1.8	Beer Sheba	5.4	25.4	31.7	35.2	35.4	37.7	37.9	38.4	39.0	35.8	30.9	26.5	23.5	20.0

## C. JORDAN RIFT ח' י י ל ל ש ש ש

Month	XII	XI	X	VIII	VII	VI	V	IV	III	II	I	Station	Month	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I
3.4	6.8	11.6	15.8	18.0	17.1	14.6	9.9	6.3	3.0	1.5	1.7	Dafna	5.4	25.9	31.7	35.8	38.4	39.3	33.0	38.8	37.4	34.0	29.1	25.0	22.4
8.3	12.4	16.5	20.7	22.8	21.6	19.0	14.4	9.8	7.2	6.1	6.3	Tiberias, Qir. Shemuel נחלות קירית שמואל	5.4	26.4	32.7	33.1	40.3	41.1	41.4	39.8	35.8	30.0	25.2	23.2	20.0
6.0	10.0	14.4	18.4	21.2	19.7	17.0	12.8	7.9	5.4	4.2	4.5	Deganya A	5.4	26.7	32.8	37.9	39.8	40.6	40.8	39.9	39.5	34.7	29.6	25.4	23.4
6.5	10.8	16.4	19.5	21.7	21.1	18.5	14.9	9.7	6.5	6.4	5.4	Jericho	5.4	25.5	31.0	42.3	41.5	42.6	42.5	42.9	39.3	33.2	27.1	24.3	20.0
8.3	12.6	17.8	21.9	24.3	23.7	21.3	16.6	11.8	9.0	7.1	6.9	Sedom, Factory סדום, כביש נחלות	5.4	26.7	32.7	33.7	41.2	44.1	45.0	42.7	38.6	32.2	27.0	25.0	20.0
6.1	10.6	15.8	20.6	22.7	20.0	15.6	11.8	9.0	5.8	4.9	4.9	Elat אילת	5.4	23.0	33.7	38.8	41.7	43.8	44.1	43.1	41.6	37.8	33.3	29.9	25.8



ט ב ל ה  
TABLE VIII  
טמפרטורת המינימום המוחלטת ( $^{\circ}\text{C}$ )

STATION	Month												חודש	התחנה
	שנה Year	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I	
<b>A. COASTAL REGION</b>														
Acre Date	-0.5 6.2.1950	1.5 1.1953	4.5 30.1953	10.0 21.1956	12.0 29.1956	15.1 15.1929	15.5 3.1932	11.7 10.1939	7.5 2.1932	4.2 2.1946	1.2 3.1928	-0.5 6.1950	0.0 23.1957	עכו תאריך
Haifa, Lower Town Date	-1.6 23.1.1907	0.2 28.1924	5.0 29.1933	13.0 23.1899	16.5 28.1938	19.0 9.1900	19.0 4.1939	14.6 11.1932	9.6 1.1908	6.0 1.1956	2.0 3.1928	(0.0) 6.1950	-1.6 23.1907	חיפה, מתחם תאריך
Haifa, Mt. Carmel Date	-3.0 6.2.1950	3.2 19.1953	4.0 30.1953	13.5 22.1941	15.0 10.1953	19.4 22.28.1949	18.0 5.1949	14.2 2.1943	11.3 6.1944	5.0 6.1943	0.5 6.1950	-3.0 27.1950	-1.0 27.1950	חיפה, הר הכרמל תאריך
Greater Tel Aviv Date	-1.9 7.2.1950	-1.1 31.1878	3.3 20.21.1908	7.2 30.1878	10.0 29.1903	15.0 22.1878	13.9 1.5.1874	10.0 1.2.1874	4.4 7.10.1878	2.5 2.1946	1.0 22.23.1945	-1.9 2.1048	-1.5 7.1950	תל אביב רבתי תאריך
Lod-Ramla Date	-2.5 30.1.1950	-0.7 12.1953	0.8 26.1959	6.7 21.1956	9.5 29.1956	14.6 9.1951	14.0 2.1952	9.5 6.1957	5.9 1.1956	0.5 2.1946	-0.5 2.1948	-2.2 7.1950	-2.5 30.1950	לוד-רמלה תאריך
<b>B. HILL REGION</b>														
Mt. Kena'an Date	-9.0 6.2.1950	-2.4 20.1953	-1.7 29.1053	5.9 14.1948	10.7 30.1949	13.0 22.1949	12.2 2.1952	9.1 2.1943	5.7 1.1948	0.2 6.1940	-3.0 6.1943	-9.0 6.1050	-6.4 5.1942	הר כנעם תאריך
Tabor, Agr. School Date	-5.4 7.2.1950	0.0 21.1953	0.2 29.1953	10.2 14.1948	14.5 28.1956	17.4 6.1040	15.6 12.1958	10.4 3.1943	7.9 6.1044	3.5 1.1056	-0.3 24.1942	-5.4 7.1950	-1.2 23.1957	תבור, בית הספר החקלאי תאריך
Ramat Dav., Aerod. Date	-11.5 7.2.1950	-2.8 31.1948	-0.4 31.1953	4.4 15.1948	10.3 11.1953	16.1 22.1949	14.3 3.1953	10.5 3.1949	5.0 0.1944	-0.6 2.1946	-1.3 8.1955	-11.5 7.1950	-5.3 8.1949	רמת דוד, ש. תעופה תאריך
Heftsbah-Gilboa' Date	-4.6 7.2.1950	1.2 31.1948	3.2 29.1953	10.6 14.1948	14.4 10.1953	19.0 22.1949	16.9 12.1958	12.7 3.1943	8.3 1.1948	2.8 2.1946	0.4 2.1948	-4.6 7.1950	-0.2 6.1942	חפטסיה-gilboa' תאריך
Jerusalem Date	-6.7 23.1.1907	-5.0 22.1905	-0.6 20.1908	0.0 24.1871	5.6 17.27.1871	10.6 23.26.1871	9.4 2.1871	7.2 2.1900	3.3 13.1901	-1.1 6.1886	-2.4 13.1910	-5.1 6.1950	-6.7 25.1907	ירושלים תאריך
Beit Jimal Date	-3.0 27.1.1925	0.7 27.1924	4.0 19.1953	11.9 27.1024	11.1 12.1922	16.5 1.1926	15.6 13.1922	11.3 12.1933	9.4 1.1926	4.5 6.1949	0.5 6.1643	-2.3 6.1950	-3.0 27.1925	בית ג'מאל תאריך
Beer Sheba Date	-5.0 31.1.1925	0.5 11.1045	2.5 30.1953	6.0 16.1926	9.4 17.1928	12.0 31.1934	12.0 8.1923	8.0 3.1928	4.5 2.1932	0.0 2.1946	-1.5 23.1945	-4.0 7.1950	-5.0 31.1925	באר שבע תאריך
<b>C. JORDAN RIFT</b>														
Dafna Date	-5.2 6.2.1950	0.4 31.1948	0.4 29.1953	9.2 15.1948	12.6 28.1956	17.0 13.1940	15.8 25.1980	12.5 2.1940	6.8 1.1948	2.4 1.1956	0.8 3.1950	-5.2 6.1950	-2.0 8.0.1940	דפנה תאריך
Tiberias Date	-3.3 27.12.1898	-3.3 27.31.1898	4.4 19.1908	10.0 14.15.1808	10.0 19.1804	13.3 9.1898	13.9 31.1898	13.8 5.1939	9.4 6.9.1898	6.1 11.1806	3.9 21.1898	-1.0 21.1930	-3.3 21.1911	טבריה תאריך
Sedom Date	3.0 24.1.1957	5.5 13.1950	6.4 26.1958	15.0 30.1956	19.5 28.1956	23.0 16.1958	21.5 1.1954	19.6 3.1943	11.5 7.1050	8.5 1.2.1956	6.4 1.1945	4.0 3.4.1957	סdom תאריך	
Eilat Date	0.9 7.2.1950	3.0 12.1953	5.3 30.1953	13.5 27.30.1949	18.8 30.1955	20.2 15.1045	21.3 5.1952	17.0 27.1945	13.8 4.1956	9.0 1.1056	4.9 1.1950	0.9 7.1950	1.2 24.1037	אילת תאריך



TABLE X  
Incidence (%) at 0800-0900 hours (%)  
ב-ה-ב-ל

היחסית הממוצעת בסוגה (%) at 0800° (ב-)

Month	חַדְשָׁה												Month												
	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I	STATION	הַנְּתָמֵן	הַנְּתָמֵן	הַנְּתָמֵן	הַנְּתָמֵן	הַנְּתָמֵן	הַנְּתָמֵן	Year					
<b>A. COASTAL REGION</b>																									
6	70	61	58	63	67	64	65	68	73	71	Acre	72	20.5	14.0	19.4	23.7	26.6	28.0	27.6	25.8	23.1	18.8	14.9	12.6	12.9
7	69	60	63	71	75	75	66	66	70	69	Haifa, Mt. Carmel	73	18.5	12.5	18.4	21.8	24.0	24.9	24.5	23.2	20.9	16.8	13.1	11.4	10.8
8	65	58	53	63	67	67	64	65	68	71	Tel Shalom	72	20.1	13.3	19.1	23.7	26.1	27.4	27.0	25.6	22.9	18.6	14.3	12.1	11.5
9	63	59	54	66	66	66	62	65	66	71	Nahanya	73	19.6	13.0	18.1	23.6	26.2	24.6	21.7	18.0	14.2	12.2	11.4	11.2	10.9
10	76	70	64	72	71	74	76	77	74	73	Tel Aviv, Shore	74	19.8	13.2	18.3	23.1	25.2	26.7	24.8	21.9	18.1	14.5	12.2	11.5	11.0
11	60	54	51	58	58	58	55	65	69	70	Tel Aviv, Hakirya	75	18.8	12.2	16.5	21.5	25.1	26.6	24.2	21.3	17.2	14.1	11.4	10.0	9.8
12	66	60	54	64	62	62	61	64	67	71	Lod, Airport	76	19.7	12.5	18.0	23.2	26.2	27.2	27.0	25.6	22.8	17.9	14.0	11.5	10.7
1	62	56	52	59	59	59	59	60	67	74	Gaza	77	19.5	12.6	17.8	22.4	25.6	26.8	25.3	22.5	18.1	14.4	11.6	10.8	10.5

TABLE IX

Average Temperature ( $^{\circ}\text{C}$ ) at 0800 $^{\circ}$  הנטה ל-00 $^{\circ}$  ( $^{\circ}\text{C}$ ) גראדיאנט

Month	N.S.											
	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
5	14.0	19.4	23.7	26.6	28.0	27.6	25.8	23.1	18.8	14.9	12.6	12.9
5	12.5	18.4	21.8	24.0	24.9	24.5	23.2	20.9	16.8	13.1	11.4	10.8
1	13.3	19.1	23.7	26.1	27.4	27.0	25.6	22.9	18.6	14.3	12.1	11.5
8	13.2	18.1	22.8	25.8	26.9	26.2	24.6	21.7	18.0	14.2	12.1	11.4
8	12.2	16.5	21.5	25.1	26.6	26.2	24.2	21.3	18.1	14.5	12.2	11.5
7	12.5	18.0	23.2	26.2	27.2	27.0	25.6	22.8	17.9	14.0	11.5	10.7
5	12.6	17.8	22.4	25.6	25.8	26.6	25.3	22.5	18.1	14.4	11.6	10.8

ב איזורם היברונו REGION BILLY

C. JORDAN BIEFT 179

Local Standard Time



TABLE XII  
Average Relative Humidity (%) at 1400° ساعת גאות הממוצעת (ב%)

TABLE XI  
Average Temperature (°C) at 1400° גאות הממוצעת (°C)

שָׁבֵב לְכָלָה

סִבְעַת גָּוֹתֶת תְּמִמְמָה (°C) at 1400° גאות הממוצעת (°C)

Month Year	Month					Station					Month														
	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II	I	
60	59	55	55	59	63	64	63	62	59	60	60	Acre	23.7	18.9	23.8	26.9	28.9	30.0	29.2	27.3	25.0	21.2	18.7	17.4	16.9
63	62	57	60	63	67	68	66	61	63	62	64	Haifa, Mt. Carmel	21.0	15.9	21.4	24.4	26.1	27.1	26.6	24.8	22.8	18.7	15.7	14.4	13.8
55	59	52	49	54	58	56	55	50	55	56	57	Tel Shalom	23.8	18.3	23.9	27.6	28.9	29.0	28.1	26.2	21.8	18.4	16.9	16.4	-
67	66	62	62	67	69	69	66	65	65	66	63	Natanya	23.3	18.8	23.8	26.8	29.4	28.6	26.5	24.0	20.6	18.2	17.1	16.9	-
63	60	61	61	62	66	68	66	65	65	61	62	Tel Aviv, Shore	23.0	18.7	23.2	26.3	28.1	29.1	28.5	26.6	23.7	20.4	18.1	16.9	16.9
58	59	56	56	56	60	61	59	57	56	58	57	Tel Aviv, Hakirya	23.9	18.8	23.0	27.2	29.4	30.4	29.4	27.6	24.7	21.7	19.3	17.7	17.0
50	53	51	47	50	51	50	47	44	50	52	54	Lod, Airport	24.7	19.1	24.4	28.2	29.7	31.0	30.6	29.3	27.3	22.6	19.1	17.7	17.2
61	63	63	61	60	61	63	63	59	58	60	60	Gaza	24.0	19.0	23.7	27.2	29.3	30.6	29.9	27.8	25.2	21.8	19.1	17.7	17.2

A. COASTAL REGION

50	67	49	41	43	41	39	36	38	51	62	68	71	Mt. Kena'an	19.3	11.1	18.0	23.0	26.3	28.2	27.9	26.3	23.6	17.4	11.8	9.6	8.7
45	54	41	36	42	40	39	37	36	41	52	57	60	Tabor, Agr. School	25.4	17.8	25.0	29.3	31.4	33.0	32.8	31.2	29.3	23.7	18.6	16.7	15.6
48	53	45	43	44	43	41	42	44	52	54	57	55	Ramat David, Aerod.	24.9	18.2	23.7	28.6	30.9	32.8	32.3	30.4	26.7	22.7	19.4	17.3	16.2
45	54	41	37	41	37	42	40	39	36	46	52	55	'Afula, Hospital	25.6	18.2	25.3	29.4	31.5	33.1	32.7	31.4	29.1	23.6	19.1	17.3	16.2
55	61	50	47	54	50	47	54	53	53	49	47	57	Mishmar ha'Emeq	24.4	17.7	24.2	28.1	30.0	31.3	30.8	29.4	27.4	22.3	18.4	16.7	15.9
44	54	42	37	39	36	44	52	55	56	Hofzibah, Gilboa'	27.4	19.6	26.5	31.2	35.2	35.9	35.0	33.5	31.3	25.8	20.6	18.5	17.5			
44	57	42	36	38	39	38	36	33	42	53	55	55	Beit Shean	27.7	19.7	26.7	31.3	34.1	35.7	35.6	34.0	31.9	26.3	20.7	18.6	17.7
47	57	43	39	44	43	42	38	38	48	53	59	59	Jenin	25.3	17.8	24.6	29.9	31.3	32.7	32.6	31.4	29.2	23.8	19.1	16.7	16.0
51	65	51	42	47	43	44	41	40	51	62	64	67	Ramallah	19.9	12.3	18.7	23.4	26.1	27.9	27.4	26.2	24.0	18.3	13.0	11.2	10.4
51	63	50	45	48	44	43	42	51	60	62	66	66	Jerusalem, Palace Hotel	21.0	13.6	19.8	24.3	27.0	28.8	28.4	27.2	25.2	19.6	14.3	12.4	11.6
47	55	47	43	45	43	41	42	38	46	52	52	56	Beit Jimal	24.4	17.6	23.6	27.7	29.8	31.7	31.3	30.9	28.0	22.6	18.6	16.5	15.6
43	52	45	40	42	38	36	31	35	49	51	58	58	Beth Sheba	25.4	18.2	24.1	28.4	30.5	32.8	32.6	31.2	29.4	24.2	19.2	17.4	16.3

B. HILL REGION

50	67	49	41	43	41	39	36	38	51	62	68	71	Mt. Kena'an	19.3	11.1	18.0	23.0	26.3	28.2	27.9	26.3	23.6	17.4	11.8	9.6	8.7
45	54	41	36	42	40	39	37	36	41	52	57	60	Tabor, Agr. School	25.4	17.8	25.0	29.3	31.4	33.0	32.8	31.2	29.3	23.7	18.6	16.7	15.6
48	53	45	43	44	43	41	42	44	52	54	57	55	Ramat David, Aerod.	24.9	18.2	23.7	28.6	30.9	32.8	32.3	30.4	26.7	22.7	19.4	17.3	16.2
45	54	41	37	41	37	42	40	39	37	46	52	55	'Afula, Hospital	25.6	18.2	25.3	29.4	31.5	33.1	32.7	31.4	29.1	23.6	19.1	17.3	16.2
55	61	50	47	54	50	47	54	53	53	49	47	57	Mishmar ha'Emeq	24.4	17.7	24.2	28.1	30.0	31.3	30.8	29.4	27.4	22.3	18.4	16.7	15.9
44	54	42	37	39	36	44	36	34	36	44	52	55	Hofzibah, Gilboa'	27.4	19.6	26.5	31.2	35.2	35.9	35.0	33.5	31.3	25.8	20.6	18.5	17.5
44	57	42	36	38	39	38	36	33	42	53	55	55	Beit Shean	27.7	19.7	26.7	31.3	34.1	35.7	35.6	34.0	31.9	26.3	20.7	18.6	17.7
47	57	43	39	44	43	42	38	38	48	53	59	59	Jenin	25.3	17.8	24.6	29.9	31.3	32.7	32.6	31.4	29.2	23.8	19.1	16.7	16.0
51	65	51	42	47	43	44	41	40	51	62	64	67	Ramallah	19.9	12.3	18.7	23.4	26.1	27.9	27.4	26.2	24.0	18.3	13.0	11.2	10.4
51	63	50	45	48	44	43	42	51	60	62	66	66	Jerusalem, Palace Hotel	21.0	13.6	19.8	24.3	27.0	28.8	28.4	27.2	25.2	19.6	14.3	12.4	11.6
47	55	47	43	45	43	41	42	38	46	52	52	56	Beit Jimal	24.4	17.6	23.6	27.7	29.8	31.7	31.3	30.9	28.0	22.6	18.6	16.5	15.6
43	52	45	40	42	38	36	31	35	49	51	58	58	Beth Sheba	25.4	18.2	24.1	28.4	30.5	32.8	32.6	31.2	29.4	24.2	19.2	17.4	16.3

C. JORDAN RIFT

47	58	48	39	41	42	40	48	53	57	57	Dafna	23.1	17.8	23.4	29.1	31.6	33.4	32.6	30.9	27.6	23.2	19.1	16.9	15.5		
46	59	48	39	40	41	37	38	37	45	56	61	61	Tiberias, Qir. Shemuel	27.0	18.8	25.5	30.6	33.7	35.6	35.3	33.8	31.3	25.2	19.7	17.7	16.7
48	55	49	42	40	38	35	36	35	39	46	53	58	Dezanya A	27.1	19.2	24.6	30.5	33.8	36.0	35.7	33.9	30.1	25.2	20.9	18.3	17.2
37	50	40	34	32	29	27	27	26	44	48	50	50	Jericho	29.6	21.2	27.7	33.1	35.9	37.6	37.7	36.4	33.9	29.4	23.0	20.6	19.4
33	47	39	34	31	26	24	26	25	38	45	54	58	Sedom, Factory	29.8	21.8	27.0	32.1	35.4	38.4	36.5	33.2	28.6	24.0	21.4	20.0	19.4
29	39	35	31	26	22	19	21	26	37	43	51	58	Eilat	30.1	21.8	27.0	32.4	36.2	38.6	38.0	34.0	29.4	24.6	21.7	20.3	19.4

• Local Standard Time



TABLE XIV תְּבִנָה

Average Relative Humidity (%) at 2000° Farenheit

TABLE XIII

Average Temperature ( $^{\circ}\text{C}$ ) at 2000:00 (0°) גְּדוֹלָה

Month	Station												Month														
	XII	XI	X	VII	VIII	IX	V	VI	IV	III	II	I	XII	XI	X	VII	VIII	IX	V	VI	IV	III	II	I			
Year													Year														
A. COASTAL REGION																											
1	73	69	67	71	76	78	77	77	76	74	73	71	Acre	122	19.2	13.9	18.3	22.2	24.8	26.1	25.4	23.4	20.3	16.8	14.0	12.8	12.6
2	71	70	71	78	83	84	81	81	74	74	72	70	Haifa, Mt. Carmel	17.9	13.5	18.1	20.9	22.7	23.7	23.1	21.4	19.3	15.6	12.9	11.9	11.8	
3	76	71	68	74	78	80	77	74	74	75	76	75	Tel Shalom	18.6	13.7	18.1	21.4	23.7	23.0	24.5	22.7	20.1	16.2	13.4	12.0	12.1	
4	78	76	76	74	79	81	81	81	84	81	80	79	Natanya	19.5	14.2	18.7	22.5	25.1	26.2	25.4	23.5	20.5	17.0	14.5	13.3	13.3	
5	78	76	76	76	77	76	77	77	75	72	75	74	Tel Aviv, Shore	19.6	14.1	18.2	22.5	25.6	26.6	25.8	23.9	20.7	17.2	14.9	13.2	13.1	
6	78	76	76	76	77	76	76	76	75	72	75	74	Tel Aviv, Hakirya	19.7	14.2	18.1	22.6	25.3	25.9	23.8	20.3	17.4	15.3	13.8	12.7		
7	79	76	76	74	78	79	78	79	75	74	77	75	Tel Aviv, HaPleha	18.8	13.2	17.5	21.6	24.7	26.2	25.6	23.7	20.7	17.4	15.2	13.2	11.6	
8	79	73	68	69	72	73	69	69	74	78	80	78	Lod, Airport	19.8	14.6	19.1	22.9	25.2	26.1	25.4	23.6	20.9	17.5	15.2	13.7	13.3	
9	79	78	75	78	80	78	79	79	75	72	74	74	Gaza	19.9	14.7	19.2	23.0	25.3	26.2	25.5	23.7	20.7	17.3	15.1	13.6	13.2	

ב איזור תחריה

כ. JORDAN RIFT 177 ה'ג' צדקה



TABLE XV תְּבִיבָה  
Average Daily Relative Humidity (%) ס. ק. ה. ח. ו. ה. י. מ. ה. י. מ. ה. י. מ.

STATION	Month												Month	Month
	Year	XII	XI	X	IX	VIII	VII	VI	V	IV	III	II		
<b>A. COASTAL REGION</b>														
Acre	67	67	62	60	64	69	70	68	68	67	69	67	67	67
Haifa, Mt. Carmel	69	67	62	59	64	75	76	73	67	67	69	68	69	69
Tel Shalom	65	69	62	59	67	67	65	61	64	67	69	69	69	69
Natanya	73	74	70	69	73	75	78	75	74	73	73	71	70	70
Tel Aviv, Shore	69	71	69	65	66	70	71	70	72	70	68	71	70	70
Tel Aviv, Hakirya	70	73	69	67	67	70	71	70	69	68	68	71	71	71
Lod, Airport	64	70	64	58	60	62	62	58	58	64	68	71	70	70
Gaza	70	73	72	68	68	70	72	70	70	69	67	70	70	70
<b>B. HILL REGION</b>														
Mt. Kena'an	58	73	57	52	57	58	56	51	48	45	44	44	44	44
Tabor, Agr. School	59	67	55	50	57	58	56	51	51	48	56	56	56	56
Ramat David, Aerod.	65	71	63	60	60	61	59	60	62	69	72	72	75	73
'Afula, Hospital	60	66	57	54	59	59	58	55	55	53	61	67	69	68
Mishmar ha 'Emeq	69	75	67	62	68	69	68	63	61	69	74	76	75	75
Heftsbah, Gilboa'	58	67	55	52	55	54	51	49	49	49	58	66	68	68
Beit Shean	58	68	57	51	55	55	54	50	48	48	56	67	69	67
Jenin	61	69	60	55	59	58	55	53	52	61	66	71	69	69
Ramallah	63	73	61	56	61	58	53	49	49	60	70	72	74	74
Jerusalem, Palace Hotel	62	72	62	59	64	57	55	54	50	60	70	72	74	74
Beit Jimal	60	64	59	56	61	59	57	52	52	59	63	62	64	64
Beer Sheba	58	68	60	55	58	56	52	48	48	56	62	67	70	70
<b>C. JORDAN RIFT</b>														
Dafna	61	71	61	55	57	59	56	53	54	61	66	70	70	70
Tiberias, Qir. Shemuel	57	65	56	50	49	52	51	49	56	66	70	67	67	67
Deganya A	59	68	59	53	54	54	52	51	53	60	67	71	70	70
Jericho	49	64	52	46	44	40	37	36	37	57	62	64	64	64
Sedom, Factory	43	57	49	42	40	35	33	34	35	38	46	50	56	56
Eilat	39	50	46	41	36	30	26	28	32	35	43	48	49	49

א. איזור הרים  
ב. איזור הרים  
ג. שקע הריון

עכו, הר הכרמל  
שלם, חוף  
תנה, חוף  
תל אביב, חוף  
תל אביב, חוף  
לוד, נמל התעופה  
נזה

תרכז, חוף חוף  
תמות, חוף שצפת  
עפולה, חוף חוף  
משמר העמק, גבעות  
חיפה, גבעות  
בית שאן  
ג'ין  
רמאללה  
ירושלים מלון פלאס  
ירושלים מלון פלאס  
בר גנון  
bara Shevach



TABLE XVIII טבלה XVIII

אכזרות הכהנים והעומת של רוחות וקרען (ב-/-) ומפנדיים הטעוקלייט אל עטומזק (גדון גהה)

PARQUET OF DIRECTIONS AND FORCE OF SURFACE WINDS (IN PCS MILLIG. AND WEIGHTED MEANS OF THEIR FORCE (KREAOFT))

ALL TIMES ARE LOCAL STANDARD TIMES - O.M.T. + 3      כל השעות הם אונט זמינו תקופה - א. נ. ז. מ. + 3

**רְאוּפָרֶט = R - רְאוּפָרֶט מֵהַרְאָבָוֹן = R - Rypharot Rypharot**



PERIOD OF OBSERVATIONS 1940 - 47 תקופה של obseruatons 1940-47 COORDINATES 31° 14' N 34° 47' E 270° צפון קורדינט obseruatons STATION 924-162 Beer-Sheba נסלה

	TIME 20-400																										
	1						2						3														
	8	6	18	4	30	30	4	120	2	4	27	4	2	31	66	18	134	9	20	4	16	4	24	44	12	124	
1	8	6	18	4	30	30	4	120	2	4	27	4	2	31	66	18	134	9	20	4	16	4	24	44	12	124	
2	24	2	26	4	18	16	143	28	27	13	35	4	6	23	128	18	234	20	14	38	8	22	106	46	234		
3	40	0	12	18	6	42	139	39	30	9	20	6	60	128	20	281	20	22	20	12	12	46	111	16	235		
4	30	4	12	2	36	87	30	201	9	13	13	11	29	96	20	191	12	8	12	4	26	70	14	146	146		
5				2	20	30		32	4	6	4	2	13	22		31		6	34	65	8	153					
6					4	20		24	4		9	13	4		30			2	10	4	20	28		64			
7						4		4			2	11	4		17				14	6		20					
8																											
9																											
Z	102	20	66	22	26	148	493	121	1000	76	47	99	12	29	178	470	80	1000	72	30	96	20	30	206	430	96	1000
F	1.9	2.3	2.3	2.6	2.3	3.1	3.0	3.0	2.9	2.7	3.3	2.4	2.7	3.4	3.2	3.0	2.7	2.9	2.3	2.2	2.7	3.0	2.9	3.9	3.1	2.6	

104°C 20 min									
0									
1	134		6	66	55	279		8	20
9	121	4	4	6	21	185	171	510	38
0	113			6	33	33	187	91	63
4	8			2	2	12	4	104	13
8	4					4	32	166	4125
2						73	4	103	40
Y						16	6	239	408
Z						8	4	16	257
						4		4	177
								15	85
<b>Σ</b>	<b>402</b>	<b>4</b>	<b>4</b>	<b>6</b>	<b>33</b>	<b>304</b>	<b>239</b>	<b>1000</b>	<b>204</b>
E	2.0	2.0	2.0	2.0	2.0	1.8	2.0	1.9	2.1



## RAINFALL MAP

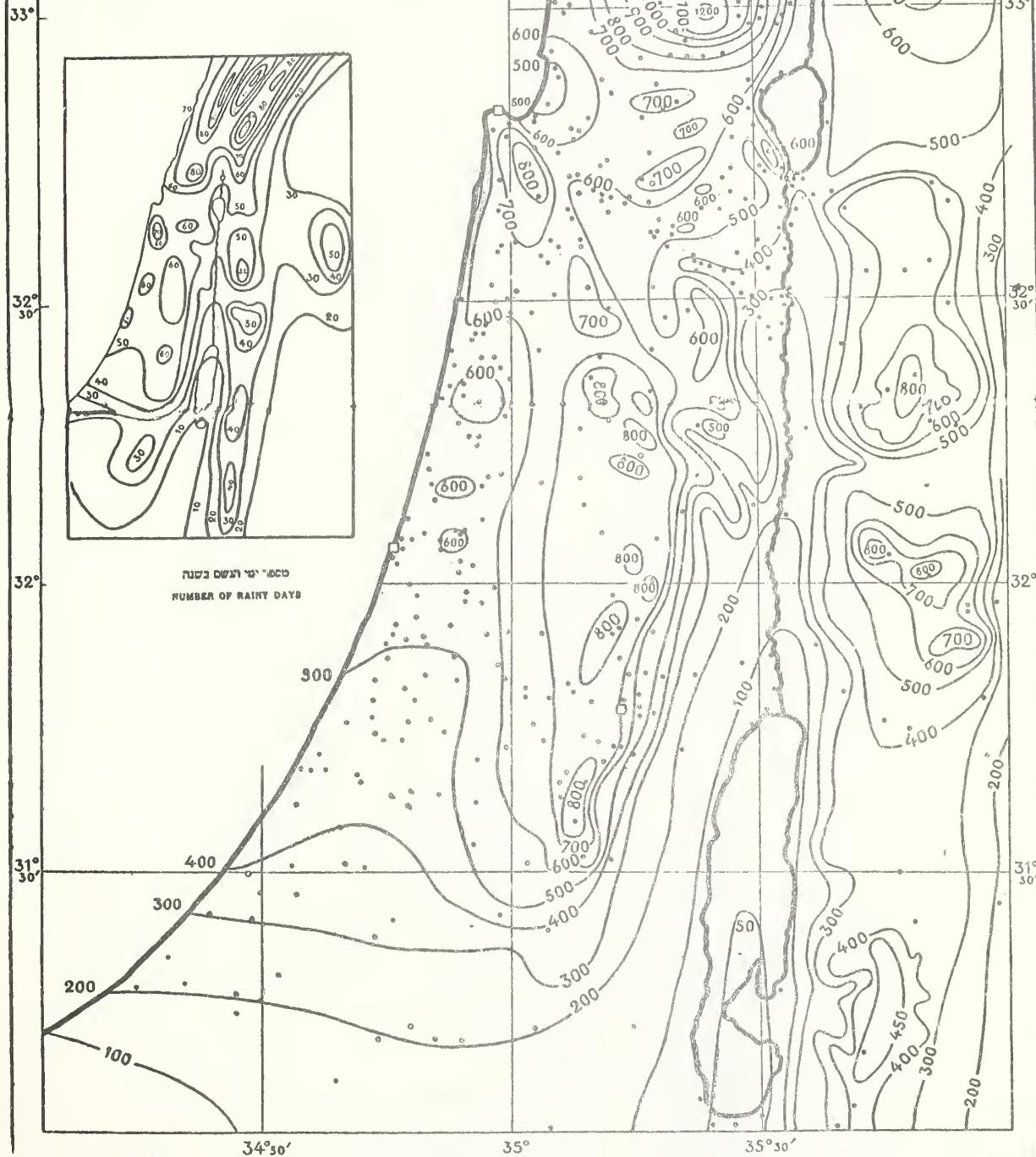
## מפת הגשמיים

Average for the period 1859-1948  
in mm

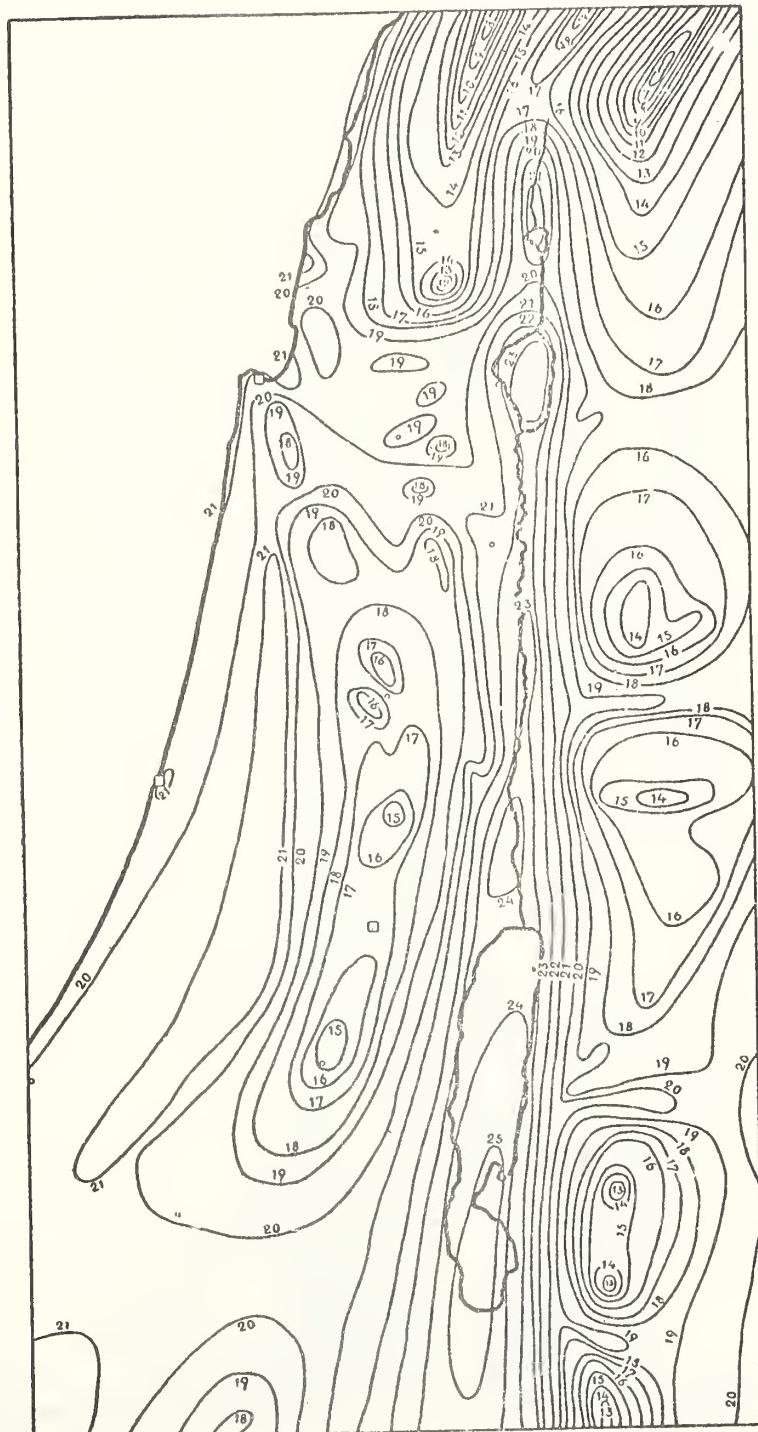
ס.מ. נחמות וחקימות 1859-1948  
ס.מ. 0.02

BY  
DR. D. ASHBEL  
JERUSALEM

באותם דרכיהם  
ד. ד. אשבל  
ירושלים

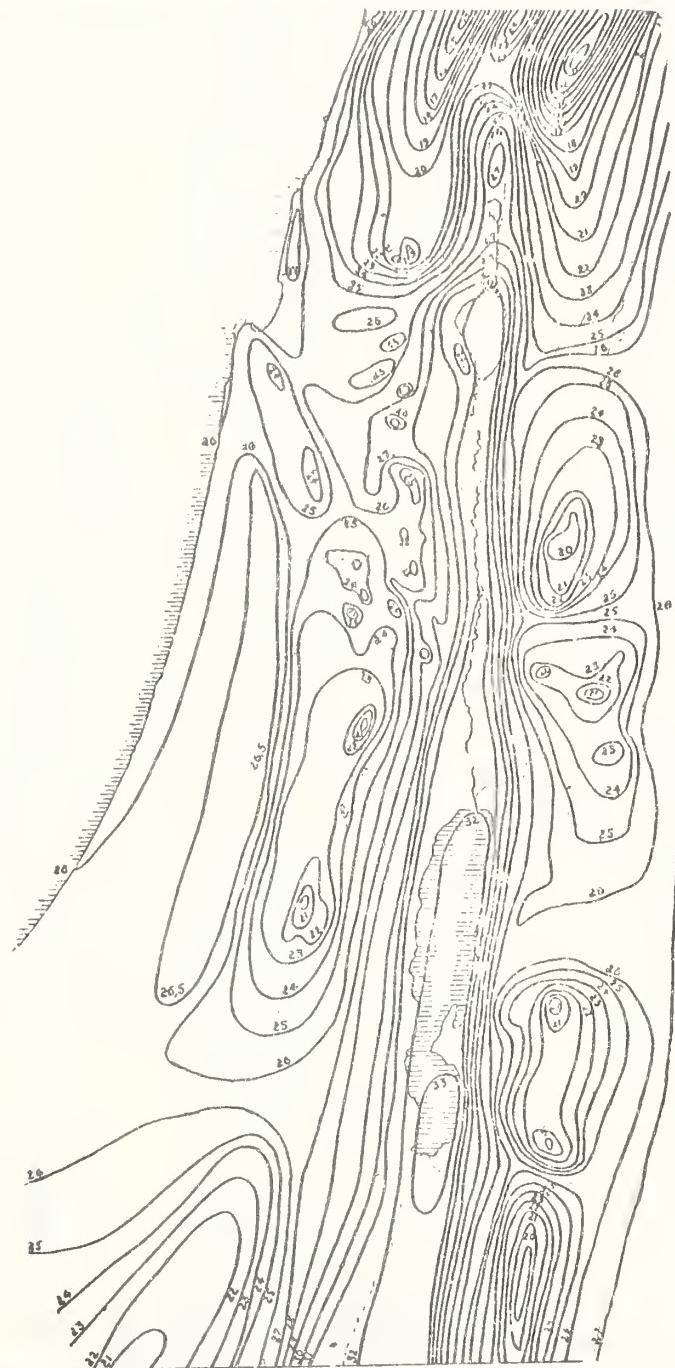






ציור 184: מפת הטמפרטורה השנתית (°C) Fig. 184: Yearly Actual Temperature Map (°C)





ציור 186: מפה הTEMPERATURE הממוצעת לחורש יולי (°C)



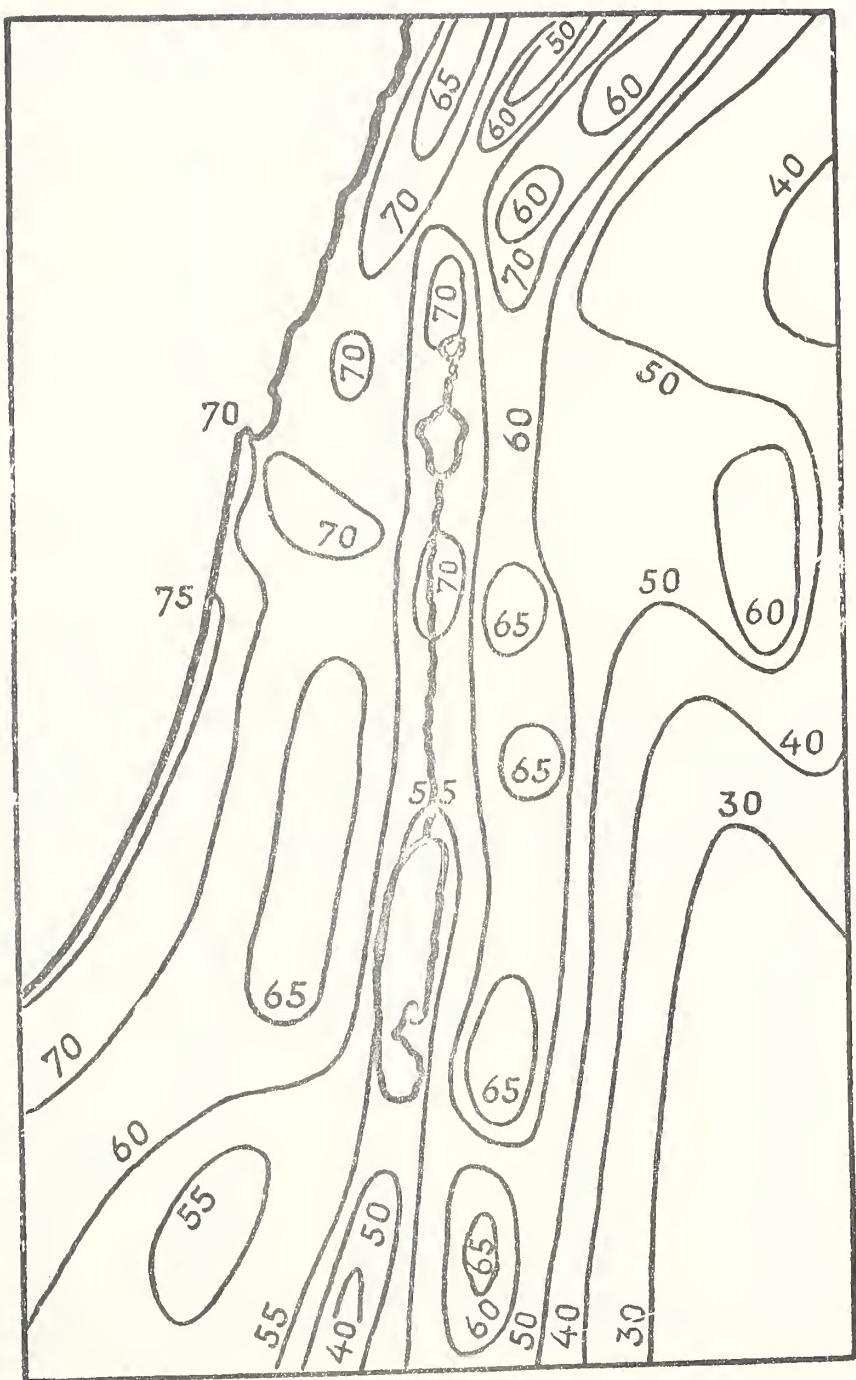


Fig. 95: Halothot hishpatit ha-shanitiyah b-%.

ציור 95: הלחות היחסית השנתית ב-%



Soil Data

Crop: LEMONS

Location: Nir-Yitzhak

Depth cm.	Classification	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30	Sand	1, 67	10.0	3.5		3.0
30-60	"	1, 58	11.5	4.4		6.0
60-90	"	1, 61	12.1	4.4		6.0
90-120	"	1, 66	12.1	3.9		4.0
120-150	"	1, 67	12.2	4.1		3.0
150-180	Loamy sand	1, 69	17.0	7.1		10.0
180-210	"	1, 70	17.0	7.4		14.0
210-240	-	1, 64	16.4	-		-
240-270	-	1, 66	16.0	-		-
270-300	-	1, 64	16.0	-		-

Crop: ALFALFA

Location: Nir-Yitzhak

Depth cm.	Classification	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
1-						
0-30	Sand	1, 70	13.4	5.8	37.5	4.5
30-60	"	1, 69	12.9	4.6	37.5	4.5
60-90	"	1, 62	13.3	4.8	40.0	5.0
90-120	"	1, 68	12.6	4.6	38.0	4.5
120-150	"	1, 65	15.5	4.5	39.0	4.5
150-180	Sandy Clay Loam	1, 69	17.4	8.0	37.6	13.0
180-210	"	1, 69	15.6	6.7	37.6	10.0
210-240	Sand	1, 64	12.4	6.0	39.5	11.0
240-270	"	1, 69	11.0	4.6	37.5	8.5
270-300	"	1, 69	10.7	4.3	39.0	9.0



Soil Data

Crop : GROUNDNUTS, Var. "Virginia"

Location : Nir-Yitzhak

Depth cm	Classifi- cation	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30	Sand	1,68	11.0	4.7		5.0
30-60	"	1,66	11.2	4.6		5.0
60-90	"	1,63	11.4	5.8		8.0
90-120	"	1,61	11.8	6.2		8.0
120-150	"	1.57	13.0	6.0		5.0
150-180	"	1,61	11.0	5.9		5.0
180-210	"	1,70	12.0	5.7		4.0
210-240	"	1,64	15.0	7.9		6.0
240-270	Loamy sand	1,68	21.9	12.3		14.0
270-300	"	1,79	21.2	11.8		13.0

Crop : GRAPES, Var. "Alfons"

Location: Sa'ad

Depth cm	Classifi- cation	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30	Loam	1,43	30.6	14.1	47.4	21.9
30-60	Clay loam	1,53	31.6	16.4	43.7	22.3
60-90	"	1,63	32.2	17.0	40.0	22.3
90-120	"	1,69	31.8	20.7	38.0	26.0
120-150	"	1,69	31.8	20.9	38.0	22.8



S o i l   D a t a

C r o p : G R A P E S , v a r . " A l f o n s "

L o c a t i o n : N i r - Y i t z h a k

Depth cm.	Classi- fication	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30	Sand	1, 66	10. 4	4. 65	38. 8	4. 0
30-60	"	1, 62	12. 0	5. 2	40. 2	6. 0
60-90	"	1, 60	13. 1	5. 0	40. 5	6. 0
90-120	"	1, 67	13. 5	5. 1	38. 5	6. 0
120-150	"	1, 71	13. 7	4. 8	35. 6	6. 0
150-180	"	1, 69	12. 7	5. 0	37. 6	4. 0
180-210	Sand Loam	1, 67	21. 8	11. 0	38. 5	10. 0
210-240	Sandy Clay Loam	1, 68	25. 8	16. 2	37. 8	16. 0
240-270	"	1, 67	25. 5	17. 2	36. 4	11. 5
270-300	Sandy Loam	1, 63	21. 0	12. 7	39. 8	10. 0

C r o p : P E A C H E S , V a r . " V e n t u r a "

L o c a t i o n : N i r - Y i t z h a k

Depth cm.	Classi- fication	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30	Sand	1, 60	10. 5	4. 5		5. 0
30-60	"	1, 60	12. 0	5. 4		6. 0
60-90	"	1, 69	13. 5	5. 7		6. 0
90-120	"	1, 64	14. 8	5. 8		6. 5
120-150	"	1, 62	15. 4	5. 2		5. 5
150-180	Loamy Sand	1, 72	17. 2	8. 3		11. 5
180-210	"	1, 70	16. 0	8. 3		12. 0
210-240	Sand	1, 69	15. 0	6. 0		10. 0
240-270	"	1, 60	15. 0	5. 6		9. 0
270-300	"	1, 65	14. 7	7. 6		8. 0



Soil Data

Crop: COTTON, Var. "Acala 4-42"

Location: S a a d

Depth cm.	Classi- fication	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30		1.31	29.7	18.4	52.0	13.3
30-60		1.42	28.4	15.1	47.0	10.8
60-90		1.48	29.1	15.6	45.7	15.5
90-120		1.49	30.2	16.3	45.4	16.0
120-150		1.50	30.8	15.9	45.0	16.0

Crop: POTATOES, var. "Uptodate"

Location: S a a d

Depth cm.	Classi- fication	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30		1.43	30.0	14.8	47.4	12.0
30-60		1.42	28.0	16.1	47.8	14.5
60-90		1.48	30.0	17.3	45.7	14.0
90-120		1.48	29.8	17.3	45.7	20.5
120-150		1.57	30.5	19.7	42.3	22.5



Soil Data

Crop: APPLES

Location: S a a d

Depth cm.	Classification	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30	Loam	1,43	30.0	14.4	47.4	19.3
30-60	"	1,46	31.4	16.0	46.3	24.0
60-90	Clay loam	1,62	34.0	19.9	40.4	24.1
90-120	"	1,62	33.2	21.1	40.4	25.7
120-150	"	1,61	33.6	21.6	40.6	24.1
150-180	-	1,69	34.5	-	-	-
180-210	-	1,69	36.5	-	-	-

Crop: PLUMS

Location: S a a d

Depth cm.	Classification	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Porosity %	CaCO <sub>3</sub> , % per weight
0-30	Sandy loam	1,45	29.8	15.3	46.6	9.4
30-60	Loam	1,54	30.8	17.5	43.4	19.8
60-90	Clay loam	1,61	31.4	19.7	40.8	-
90-120	Clay loam	1,65	32.6	19.4	39.3	-
120-150	Clay loam	1,66	33.2	20.0	39.0	21.5
150-180	Clay loam					
180-210	Clay loam					
210-240	Clay					
240-270	Clay					



Soil Data

KEFAR HAYAROK

Crop: PEACHES APPLES and PLUMS

Depth cm.	Classification	Field Density	Field Capacity % (per Volume)	Wilting point % (per Volume)	Hygroscopic Water %	CaCO <sub>3</sub> , % per weight	pH
0-30	Sand loam	1,68	26,2	13,0	1,77	0,1	7,2
30-60	" "	1,68	30,7	14,7	3,78	-	7,2
60-90	Loam	1,67	31,6	15,6	4,95	-	6,8
90-120	Clay loam	1,69	31,8	15,6	5,12	0,2	7,1
120-150	" "	1,69	32,4	15,4	5,11	0,9	7,2
150-180	" "	1,66	31,5	15,0	5,56	1,0	7,3
180-210	" "	1,67	34,9	17,2	5,94	1,3	7,4

Crop: ORANGES

Depth cm.	Classification	Field Density	Field Capacity % (per Volume)	Wilting point % (per Volume)	Hygroscopic Water %	CaCO <sub>3</sub> , % per weight	pH
0-30	Loam Sand	1,67	28,6	14,2	2,03	-	6,6
30-60	Loam	1,68	30,9	15,0	4,00	-	6,5
60-90	Clay Loam	1,70	32,3	16,2	4,92	0,4	7,2
90-120	" "	1,72	33,9	16,8	5,01	1,7	7,4
120-150	" "	1,71	35,0	17,5	5,23	1,5	7,4
150-180	" "	1,70	36,7	17,8	5,66	1,3	7,5
180-210	" "	1,68	36,6	18,2	5,87	1,4	7,5



Crop: GRAPES

Depth. cm.	Classifi- cation	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Hyscopic Water %	CaCO <sub>3</sub> , % per weight	pH
0-30	Sand loam	1, 71	23, 4	12, 1	2, 50	0, 6	7, 1
30-60	Loam	1, 63	25, 9	13, 2	4, 30	0, 2	7, 0
60-90	Clay loam	1, 59	26, 2	13, 2	4, 79	0, 3	6, 7
90-120	" "	1, 72	28, 4	14, 5	4, 86	1, 4	7, 3
120-150	" "	1, 81	28, 2	14, 0	3, 74	3, 4	7, 2
150-180	" "	1, 74	27, 1	13, 2	3, 64	1, 1	7, 2
180-210	" "	1, 78	27, 5	13, 7	3, 37	0, 8	7, 3

Crop: GRAPEFRUIT

Depth cm.	Classifi- cation	Field Density	Field Capacity % (per volume)	Wilting Point % (per volume)	Hyscopic Water %	CaCO <sub>3</sub> , % per Weight	pH
0-30	Sand loam	1, 66	26, 1	13, 2	3, 83	0, 2	7, 1
30-60	Loam	1, 62	31, 3	15, 5	3, 90	0, 2	7, 3
60-90	Clay loam	1, 65	32, 7	15, 6	5, 47	0, 3	7, 5
90-120	" "	1, 63	33, 6	16, 2	5, 64	1, 7	7, 7
120-150	" "	1, 60	53, 8	17, 3	5, 94	1, 2	7, 8
150-180	" "	1, 61	37, 0	17, 8	6, 60	1, 2	7, 9
180-210	" "	1, 67	37, 6	18, 2	6, 42	1, 5	8, 0



CROP AND IRRIGATION DATA

Type of crop	Distance between trees	Distance between rows	Location	
Oranges	4 meters	6 meters	Kfar Hayarok	
Grapefruit	"	"	"	"
Apples	"	4 meters	"	"
Peaches	"	5 meters	"	"
Plums	"	"	"	"
Grapes	2 meters	3 meters	"	"
Apples	4 meters	5 $\frac{1}{2}$ meters	Saad	
Plums	"	"	"	
Grapes	2 meters	3 meters	"	
Peaches	4 meters	5 meters	Nir Itzhak	
Lemons	"	6 meters	"	"
Grapes	2 meters	3 meters	"	"

Note: only in the Apples in SAAD there is a cover crop of Rhodes Grass.



CROP AND IRRIGATION DATA 1963

A L F A L F A

1 9 6 3

Nir - Yitzhak

(Depth of sampling : 15<sup>0</sup> cm)

Amount given m <sup>3</sup> /dunam	Date of Irrigation	Irrigation Interval, Days	Moisture Deficit		Sampling Date
			Daily	Total	
Rain 3.6 + 25	16.3		0.5	6.9	26.2.63
					12.3.63
					17.3.63
					25.3.63
70	1.4	16	6.5	26.1	29.3.63
					4.4.63
60			5.65	67.8	16.4.63
50	29.4				26.4.63
					2.5.63
70	5.5	6			3.5.63
					7.5.63
54	14.5	9	8.5	33.9	11.5.63
					16.5.63
70	25.5	11	7.0	34.8	21.5.63
	3.6	8			27.5.63
					5.6.63
					6.6.63
	17.6	14	6.8	42.4	13.6.63
					19.6.63
100	28.6	11	7.4	44.4	25.6.63
					30.6.63
135	26.7	28	4.0	59.6	15.7.63

\*) IMPORTANT REMARK:

m<sup>3</sup>/dunam is equivalent to mm of R.



A L F A L F A (Cont.)

1963

Nir - Yitzhak

(Depth of sampling ; 150 cm)

Amount given $m^3/dunam$	Date of Irrigation	Irrigation Interval, .Days	Moisture Deficit		Sampling Date
			Daily	Total	
					28.7.63
			7.0	7	29.7.63
72	7.8	12	7.45	52.2	5.8.63
					9.8.63
65	18-19.8	11.5	7.9	63.0	17.8.63
					21.8.63
70	31.8	12.5			31.8.63
85	3.9	3			3.9.63
					6.9.63
65	19.9	16	4.25	55.2	19.9.63
					23.9.63
90	28.9	9	14.7	58.8	26.9.63
					1.10.63
55	9.10	11	6.5	45.3	8.10.63
7	Rain 20-22.10				12.10.63
54	25-27.10		5.5	59.4	24.10.63
					29.10.63
54	10.11	15	4.4		7.11.63
					10.11.63

Remarks : Night irrigation, 90% efficiency

Extent of crop: 66 dunam

Average fresh weight per mowing (in six mowings) : 1210 kg/dunam



A P P L E S var. Grand-Alexander

1 9 6 3

S a a d

(Depth of sampling : 150 cm)

Amount given m <sup>3</sup> /dunam	Date of Irrigation	Irrigation Interval Days	Moisture Deficit		Sampling Date
			Daily	Total	
60	6. 3	-			
	Rain	-	-	47.7	26.3.63
140	24. 4	-	1.45	87.3	22.4.63
			-	61.8	14.5.63
130	26. 5	32	3.9	97.2	23.5.63
				97.8	12.6.63
1 150	22. 6	26	-	109.2	20.6.63
-	-	-	-	22.5	25.6.63
-	-	-	-	75.9	2.7.63
130	14. 7.	23	-	105.0	11.7.63
-	-	-	-	54.0	18.7.63
-	-	-	5.1	94.8	26.7.63
120	4. 8	21	2.65	110.7	1.8.63
-	-	-	-	39.0	8.8.63
			5.3	57.0	15.8.63
130	25. 8	21		108.3	21.8.63
				11.7	27.8.63
-	-	-	3.1	39.6	5.9.63
140	29. 9	34	3.4	107.4	25.9.63
	-	-	-	96.0	1.10.63
Rain, 21-25.10			4.0	-	16.10.63
Rain, 1-4.11			3.8	-	31.10.63
10.11			-	-	7.11.63
			-	-	13.11.63
-	-	-	2.3	16.8	20.11.63

Remarks : Day irrigation, 85% efficiency

Date of planting : 1953

Extent of orchard : 45 dunam

Weight of crop : 2.5 tons/dunam



G R A P E S , var. Alfons

1963

Nir - Yitzhak

(Depth of sampling: 210 cm)

Amount given m <sup>3</sup> /dunam	Date of Irrigation	Irrigation Interval, Days	Moisture Deficit Total	Sampling Date
100	11.4			25.3.63
100	30.4	19	0	3.4.63
			41.1	2.5.63
			59.8	11.5.63
	30.5	30	64.6	17.5.63
			45.3	28.5.63
130	1.7	33	87.3	11.6.63
			17.1	25.6.63
70	17.7	16	79.6	3.7.63
			45.6	14.7.63
150	4.9	49	86.1	23.7.63
			0	8.8.63
			21.6	7.9.63
120	30.10	56	79.6	16.9.63
				30.9.63
				25.2

Remarks : Night irrigation, 85% efficiency

Extent of crop : 58 dunam

Date of planting : 1955

Weight of crop : 1.5 tons/dunam



GRAPES var. Alfons

1 9 6 3

S a a d

(Depth of sampling: 150 cm and three times to 300 cm)

Amount given m <sup>3</sup> /dunam	Date of Irrigation	Irrigation Interval	Moisture Deficit		Sampling Date
			Daily	Total	
150	6/2			63	27.3.63
150	19/5	103	1, 4	130	14.5.63
-	-	-	-	-	23.5.63
-	-	-	3, 55	59, 4	6.6.63
-	-	-	3, 8	97, 6	18.6.63
180	7/7	49	3, 7	157, 5	4.7.63
-	-	-	-	-	11.7.63
-	-	-	-	74, 7	26.7.63
-	-	-	-	135, 9	15.8.63
180	1/9	55	4, 41	140	16.8.63
-	-	-	-	-	5.9.63
-	-	-	4.4	92.1	26.9.63
-	-	-	-	-	8.10.63
-	-	-	2.4	132.6	16.10.63
-	-	-	1.9	151.8	21.10.63
-	-	-	-	159.3	13.11.63
-	-	-	2.3	168.6	17.11.63

Remarks : Day irrigation 85% efficiency

Extent of crop : 40 dunam Date of planting : 1956

Weight of crop : 2.6 tons/dunam



GROUNDNUTS, var. Virginia

1963

Nir - Yitzhak

(Depth of sampling : 150 cm)

Amount given m <sup>3</sup> /dunam	Date of Irrigation	Irrigation Interval Days	Moisture Deficit mm		Age of Crop	Sampling Date
			Daily	Total		
42	1.5	-		21.0	18	29.4.63
-	-	-	2	-	22	3.5.63
42	16.5	15	1,9	-	29	10.5.63
-	-	-	2,2	-	37	18.5.63
42	1.6	15	2,0	24.0	49	30.5.63
-	-	-	-	-	33	3.6.63
-	-	-	-	22.5	59	9.6.63
40	16.6	15	3	19.3	62	12.6.63
-	-	-	-	-	68	18.6.63
63	28.6	12	4	41.0	74	24.6.63
-	-	-	-	12.0	80	30.6.63
47	3.7	5	-	40.8	81	1.7.63
-	-	-	-	38.0	85	5.7.63
54	10.7	7	5.1	53.7	88	8.7.63
-	-	-	-	35.4	92	12.7.63
45	18.7	8	6	53.0	95	15.7.63
-	-	-	-	23.7	100	20.7.63
52	26.7	8	6	61.8	103	23.7.63
-	-	-	-	37.0	109	29.7.63
52	2.8	7	6.4	68.1	111	31.7.63
-	-	-	-	52.8	116	5.8.63
46	11.8	9	6.4	76.0	121	10.8.63
-	-	-	-	22.8	124	13.8.63
48	18.8	7	6	41.4	129	18.8.63
-	-	-	-	-	132	21.8.63
40	25.8	7	6.4	77.6	136	25.8.63
						28.8.63
						11.11.63

Remarks : Night Irrigation , 90% efficiency

Date of sowing : 11.4.1963

Extent of crop : 100 dunam

Date of cropping : 10.9.1963

Weight of crop : 550 kg/dunam



L E M O N S

1 9 6 3

Nir - Yitzhak

(Depth of sampling : 150 cm)

Amount given m <sup>3</sup> /dunam	Date of Irrigation	Irrigation Interval, Days	Moisture Deficit		Sampling Date
			Daily	Total	
	4.3		1.2	6.3.63	
Rain 11.0			2.8	48.6	23.3.63
80	2.5			63.3	26.4.63
				13.2	4.5.63
			3.3	46.5	14.5.63
96	30-31.5	28.5	3.35	86.7	26.5.63
				0	2.6.63
150	26.6	26.5	4.4	96.3	24.6.63
				0	28.6.63
			9.9	18.6	30.6.63
	19.7	23	6.1	67.1	8.7.63
				8.4	21.7.63
			3.8	80.7	9.8.63
60	14.8	26		90.2	14.8.63
				43.3	16.8.63
80	10.9	26	1.7	86.7	10.9.63
				-	12.9.63
75	2.10	22	3.5	64.5	27.9.63
				26.4	4.10.63
80	30.10	28	1.9	73.8	29.10.63
				0	1.11.63
			3.0	42.6	15.11.63

Remarks : Day irrigation, 85% efficiency

Date of planting : 1958

Extent of orchard : 36 dunam



P E A C H E S , var. Ventura

1 9 6 3

N i r - Y i t z h a k

(Depth of sampling : 210 cm)

Amount given m <sup>3</sup> /dunam	Date of Irrigation	Irrigation Interval Days	Moisture Deficit		Sampling Date
			Days	Total	
130	22.3			116	20.3.63
				0	24.3.63
120	3.5	42	3.3	126.8	27.4.63
				23.0	5.5.63
				9.5	15.5.63
130	25.5	22	5.4	145.6	20.5.63
				53.5	27.5.63
170	15.6	21	7.9	164.4	10.6.63
				31.2	17.6.63
130	29.6	14	10.0	140.8	28.6.63
				58.8	2.7.63
130	11.7	12	13.2	174.8	10.7.63
				8.1	14.7.63
				144.3	25.7.63
75	10.8	30	1.4	166.2	9.8.63
				81.9	12.8.63
125	5.9	26	5.4	189.6	1.9.63
				82.5	7.9.63
				8.2	16.9.63
150	2.10	27	9.0	200.3	21.9.63
120	2.11.	31		23.7	4.10.63
					4.11.63

R e m a r k s : Day irrigation, 85% efficiency

Date of planting : 1957

Extent of orchard : 23 dunam

Weight of crop : 1.0 tons/dunam



PLUMS, var. Metley

1963

Saad

(Depth of sampling : 150 cm)

Amount given $m^3$ /dunam	Date of Irrigation	Irrigation intervals Days	Moisture Deficit		Sampling Date
			Days	Total	
80	26.2				
-	-	-	-	32	27.3.63
130	7.5	70	1.85	104	5.5.63
-	-	-	-	104.7	4.6.63
30	10.6	34	6.65	144.6	10.6.63
-	-	-	-	60.0	18.6.63
-	-	-	5.9	142.8	2.7.63
-	-	-	2.2	178.1	18.7.63
180	28.7	48	2.9.	198.3	25.7.63
-	-	-	-	0	4.8.63
-	-	-	9.5	67.7	15.8.63
-	-	-	3.9	114.0	27.8.63
150	17.9	51	4.5	190.0	15.9.63
			-	11.5	26.9.63
			3.6	55.7	8.10.63
			2.9	98.4	7.11.63
			2.1	121.8	18.11.63

Remarks : Day Irrigation, 85% efficiency

Date of Planting : 1952

Extent of orchard : 56 dunam

Weight of crop : 1.0 tons/dunam



ADDENDUM TO PREVIOUS PLANT DEVELOPMENT DATA

Alfalfa, Nir Yitzhak (See p. 11)

Remarks	Height of plants cm.	Dry Matter %	Yield Kg.	Date	Cutting No.
	45 cm.	31.4	1000 kg.	20.4.63	I
	55	30	1500	30.5.63	II
	68	35.0	1800	22.6.63	III
Not irrigated (failure of supply)	40		800	17.7.63	IV
	70	38	1700	15.8.63	V
			1000	15.9.63	VI
Attacked by prodenia			1000	9.10.63	VII
			800	24.10.63	VIII
			<u>1000</u>	6.11.63	IX
Total yield , kg.			10500		

Groundnuts, Nir-Yitzhak (See p. 11)

Planted in rows	Plant Height	Width	Date
	4 cm.	6 cm.	29.4.63
5 x 60 cm.	6 "	10 "	10.5.63
	7 "	10 "	14.5.63
	13,5	15 "	30.5.63
	14 cm.	15 "	3.6.63
	14 "	16 "	9.6.63
	15 "	18 "	12.6.63
	15 "	20 "	18.6.63
	20 "	30 "	24.6.63
	30 "	45 "	30.6.63
	40 "	60 "	10.7.63
	45 "	60 "	15.7.63



O R C H A R D S

Apples, Sa'ad

Foliation 20/4                              Loss of foliage from 15/11

Date of gathering: 20/8 - 20/9

Grapes, Sa'ad

Foliation 15/5                              Loss of foliage from 10/11

Harvest 5/10 - 20/10

Plums, Sa'ad

Foliation 15/4                              Loss of foliage from 15/10

Picking 5/6 - 15/6

Grapes, Nir-Yitzhak

Foliation 1/5                              Loss of foliage from 1/11

Harvest 1/9 - 20/9

Peaches, Nir-Yizhak

Foliation 10/4                              Loss of foliage from 15/10

Picking 10/6 0 20/6.



## CROP AND IRRIGATION DATA 1964

Crop : Grapes, Var.: Danug

Location : Saad

Date of Planting : 1956

Extent of Orchard : 45 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
28.4.64						
10.5.64				12.5.64	120	Foliation 10.5.64
22.6.64			29	10.6.64	120	
28.6.64	17	2.8				
1.7.64						
8.7.64	30	3.0				
13.7.64	14.7	2.9				
16.7.64	8.1	2.7				
20.7.64						
23.7.64	9.3	3.1				
27.7.64	23.1	3.3	48	28.7.64	130	
3.8.64						
12.8.64	33.6	3.7				
18.8.64						
25.8.64	54.6	4.2				
2.9.64	26.7	3.6				
10.9.64	32.4	4.1	44	11.9.64	15	
23.9.64						
1.10.64						
6.10.64	42.0	3.2				Harvest
12.10.64	45.3	4.1				10/11 - 20/11
4.11.64						Loss of foliage from 1.1.65
16.11.64						



Crop : Plums Var.: Metley

Location : SAAD

Date of Planting : 1957

Extent of Orchard : 56 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
31.3.64						Foliation 19.3.64
20.4.64	88.0	4.0				
21.4.64				8.4.64	115	
26.4.64	11.0	2.2				
14.5.64			20	18.5.64	130	Picking
9.6.64			20	19.6.64	200	25/5 - 15/6
15.6.64	24.0	4.0				
25.6.64						
28.6.64	16.5	5.5				
1.7.64						
5.7.64						
8.7.64	48.0	4.8				
13.7.64	32.0	4.0				
20.7.64	27.0	3.8				
27.7.64	22.2	3.2				
30.7.64						
3.8.64	15.6	2.2	45	3.8.64	150	
12.8.64						
18.8.64						
14.9.64	78.0	2.9				
6.10.64						
12.10.64						
22.10.64						
3.11.64						
9.11.64	10.2	1.7				Loss of foliage from 1.11.64



Crop : Apples Var.: Grand-Alexander

Location : SAAD

Date of Planting : 1953

Extent of Orchard : 45 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
26.4.64				30.4.64	90	Foliation 8.4.64
22.5.64	96.1	4.2	24	24.5.64	100	
19.6.64	130.0	5.0	28	21.6.64	140	
1.7.64						
8.7.64	37.5	5.4				
13.7.64	27.7	5.5	25	16.7.64	90	
20.7.64						
23.7.64						
27.7.64	33.6	4.8				
30.7.64						
3.8.64	27.9	4.0	18	3.8.64	100	
12.8.64						
18.8.64	27.2	4.5				Date of gathering
25.8.64			22	25.8.64	100	23/8 - 20/9
2.9.64						
14.9.64			21	15.9.64	90	Weight of crop
1.10.64						2.5 tons/dunam
6.10.64			19	4.10.64	80	
12.10.64	27.0	4.5				
22.10.64	43.0	4.3		25.10.64	100	
9.11.64						Loss of foliage from 15/12



Crop : Cotton Var.: Acala 4-42

Location : SAAD

Date of Planting : 20.4.64

Extent of Orchard : 100 dunam

Depth of Sampling : 150 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
22.6.64				13.6.64	80	
25.6.64	4.5	1.5				
28.6.64	5.4	1.8				
1.7.64	10.8	3.6				
8.7.64	26.5	3.8				
16.7.64			32	15.7.64	100	
20.7.64	13.2	3.3				
23.7.64						
27.7.64	24.8	3.5				
30.7.64	17.2	5.7				
3.8.64	20.4	5.1	21	5.8.64	100	
12.8.64						
18.8.64						
25.8.64			17	22.8.64	100	
2.9.64						
14.9.64	39.7	3.3				
1.10.64	42.8	2.5				
12.10.64						
22.10.64						
9.11.64						



Crop Data - Kfar Hayarok

Crop : Apples Var. : Grand Alexander

Location : Kfar Hayarok

Date of Planting : 1957

Extent of Orchard : 12 dunam

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
6.4.64						
14.4.64				16.4 rain	9 min	Foliation 15.4.64
24.4.64				22	22.4.64	40
6.5.64	23.5	2.0	19	14.5.64	60	
19.5.64						
28.5.64	28.0	3.1				
4.6.64	16.0	2.3	13	2.6.64	60	
12.6.64						
18.6.64	20.0	3.3	19	15.6.64	70	
25.6.64	15.5	2.2				
2.7.64			13	28.6.64	70	
8.7.64	15.0	2.5				
13.7.64	12.5	2.5	19	17.7.64	60	Picking 15/7-30/7
19.8.64			14	31.7.64	70	
24.8.64			19	19.8.64	60	
3.9.64						
9.9.64	17.1	2.8				
17.9.64			27	15.9.64	60	
24.9.64	18.0	2.6				
29.9.64	15.9	3.2				
8.10.64			26	11.10.64	70	
15.10.64						
28.10.64			21	1.11.64	60	Loss of foliage 1.12.64



Crop : Peaches Var.: Smith

Location : Kfar Hayarok

Date of Planting : 1957

Extent of Orchard : 5 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
25.3.64						10.3.64 Foliation
13.4.64	45.0	2.3		16.4 rain	9 mm	
29.4.64				20.4.64	40	
5.5.64	27.0	4.5				
19.5.64	46.0	3.3	23	13.5.64	60	
25.5.64			14	27.5.64	60	
4.6.64	82.0	5.1				
11.6.64			11	7.6.64	70	
16.6.64						
22.6.64	59.0	5.4	19	26.6.64	60	
29.6.64						Picking 1/7 - 15/7
6.7.64						
11.7.64	42.0	3.5	16	12.7.64	60	Weight of crop
14.7.64						3.5 tons/dunam
5.8.64	70.0	3.2	16	28.7.64	70	
18.8.64	44.5	3.4				
24.8.64			22	19.8.64	60	
3.9.64						
9.9.64						
17.9.64			25	13.9.64	80	
24.9.64	28.5	4.1				
29.9.64			16	29.9.64	80	
8.10.64						
15.10.64	9.6	1.4				Loss of foliage
28.10.64			24	23.10.64	60	from 1.11.64



Crop : Grapes Var.: Alfons

Location : Kefar Hayarok

Date of Planting : 1956

Extent of Orchard : 21 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
19.4.64						
4.5.64	27.5	1.8				
10.5.64	11.0	1.8				Foliation 15.5.64
14.5.64				14.5.64	100	
21.5.64						
27.5.64						
31.5.64	28.0	2.8				
10.6.64	17.5	1.8				
18.6.64			29	12.6.64	80	
28.6.64						
2.7.64	43.0	3.8				
14.7.64			28	10.7.64	80	Harvest
19.8.64	65.0	1.9				1/8 - 15/8
24.8.64	9.9	2.0				
3.9.64			50	29.8.64	90	Weight of crop
17.9.64	17.1	1.2				2.5 tons/dunam
24.9.64						
29.9.64	9.0	1.8				
8.10.64						
15.10.64						Loss of Foliage
28.10.64	29.1	2.2				1.12.65



Crop : Plums Var. : Ogden

Location : Kefar Hayarok

Date of Planting : 1957

Extent of Orchard : 5 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
13.4.64				16.4 rain	9 mm	
23.4.64	43.0	4.3				Foliation
30.4.64				24.4.64	40	
6.5.64	17.6	3.0	19	13.5.64	60	10.3.64
18.5.64			24	27.5.64	60	
9.6.64						
12.6.64			14	10.6.64	70	
21.6.64						Picking
1.7.64			16	26.6.64	70	18.6 - 30.6
14.7.64	39.1	3.0	18	14.7.64	60	
22.7.64			14	28.7.64	70	Weight of crop
6.8.64	53.5	3.6				3.3 tons/dunam
24.8.64			20	17.8.64	60	
3.9.64						
9.9.64	22.8	3.8	23	9.9.64	80	
17.9.64						Loss of foliage
24.9.64	23.1	3.3				
29.9.64			18	27.9.64	80	from 15.10.64
8.10.64	19.8	2.2				
15.10.64	15.3	2.2				
28.10.64			23	20.10.64	60	
12.11.64						



Crop : Oranges Var.: Shamouti

Location : Kefar Hayarok

Date of Planting : 1957

Extent of Orchard : 25 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
6.4.64						Flowering
19.4.64	26.0	2.0		16.4 rain	9	15/3 - 15/4
30.4.64				28.4.64	50	
12.5.64	18.9	1.6	19	17.5.64	80	
20.5.64						
27.5.64						
2.6.64	20.4	3.4				
11.6.64			22	8.6.64	80	
17.6.64						
24.6.64	25.5	3.6	16	24.6.64	70	
20.7.64	106.0	4.1	18	12.7.64	80	
13.8.64	94.0	3.9	20	1.8.64	80	
24.8.64						
3.9.64			19	20.8.64	90	
17.9.64						
24.9.64	17.4	2.5	25	14.9.64	90	
29.9.64	8.7	1.7				
8.10.64			17	1.10.64	70	
15.10.64	7.2	1.0				
28.10.64			20	21.10.64	60	
12.11.64						Picking 1.1.65
						Weight of crop 2 tons/dunam



Crop : Grapefruit Var.: Marsh

Location : Kefar Hayarok

Date of Planting : 1957

Extent of Orchard : 12 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
15. 4. 64				16. 4 rain	9 mm	Flowering
24. 4. 64	34.5	3.8		28. 4. 64	30	15. 3. 64 - 15. 4. 64
5. 5. 64						
10. 5. 64						
13. 5. 64	27.0	3.4	21	19. 5. 64	50	
24. 5. 64						
26. 5. 64	36.0	2.8				
2. 6. 64						
11. 6. 64			20	8. 6. 64	70	
15. 6. 64						
25. 6. 64	53.0	3.8	18	26. 6. 64	70	
13. 8. 64	201.0	4.1	17	13. 7. 64	80	
19. 8. 64			17	30. 7. 64	85	
3. 9. 64	42.0	2.8	17	16. 8. 64	85	
9. 9. 64			18	3. 9. 64	90	
17. 9. 64						
24. 9. 64			23	26. 9. 64	70	
29. 9. 64						
8. 10. 64	24.0	2.7	19	15. 10. 64	50	
15. 10. 64			17	1. 11. 64	40	Picking 15. 11. 64
						Weight of Crop 2,5 tons/dunam



Crop : Alfalfa

Location : Kefar Hayarok

Date of Planting : 1961

Extent of Field : 25 dunams

Depth of Sampling : 150 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Date of Cutting	Weight of crop Kg/dunam
	Total	Daily					
12.4.64							
19.4.64	25.2	3.6				20.4.64	1,500
26.4.64				22.4.64	103		
7.5.64	36.9	3.4					
12.5.64	24.3	4.8				15.5.64	1,500
22.5.64			27	19.5.64	100		
29.5.64							
2.6.64	64.1	5.8				5.6.64	1,400
10.6.64			19	7.6.64	103		
16.6.64	18.0	3.0					
25.6.64	23.1	2.6				26.6.64	1,400
30.6.64			20	27.6.64	100		
7.7.64	21.6	3.2					
14.7.64						14.7.64	1,200
18.7.64			18	15.7.64	80		
22.7.64	17.1	4.3					
6.8.64			18	2.8.64	80		
27.8.64	88.4	4.2				20.8.64	1,100
31.8.64							
17.9.64			24	26.8.64	80		
29.9.64						13.9.64	1,000
5.10.64			19	14.9.64	80		
12.10.64	18.0	2.6					
18.10.64						19.10.64	1,200
1.11.64						Total Yield	10,300



Crop Data

Crop : Grapes Var. : Alfons

Location : Nir Itzhak

Date of Planting : 1955

Extent of Orchard : 58 dunams

Depth of Sampling : 300 cms

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
16.2.64						
10.3.64	32.0	1.0				Foliation
25.3.64						15.4.64
5.4.64				2.4.64	90	
12.4.64						
15.4.64						
19.4.64	17.7	2.5		21-22/4	rain 10mm	
22.4.64						
26.4.64						
29.4.64	18.1	2.6				
3.5.64						
6.5.64	8.3	2.8				
10.5.64						
13.5.64						
20.5.64	19.0	2.7	51	23/5/64	95	
24.5.64						
27.5.64						
31.5.64	16.7	3.34				
3.6.64	9.1	3.0				
7.6.64						
10.6.64	20.6	2.9				
14.6.64	15.4	3.8				
17.6.64						
21.6.64	14.8	3.7				
28.6.64						



G r a p e s II

Crop : Grapes Var. :

Location : Nir Itzhak

Date of Planting :

Extent of Orchard : dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
5.7.64						
14.7.64						Harvest
19.7.64	70.9	3.4				15/7 - 1/8
21.7.64	36.4	5.7				
28.7.64			28	23.7.64	120	Weight of crop
4.8.64						2 tons/dunam
12.8.64	70.0	5.4				
26.8.64			35	27.8.64	120	
24.9.64						Loss of foliage
19.10.64			31	27.9.64	120	1.1.65



Crop : Lemon var.: Jurica

Location : Nir Itzhak

Date of Planting : 1958

Extent of Orchard : 36 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
18.3.64						first flowering
13.4.64	33.1	1.3				15/2 - 15/3
16.4.64						
20.4.64	12.7	3.2		14.4.64	60	
24.4.64				21-22/4	rain 10mm	
27.4.64	8.4	2.8				
30.4.64	5.5	1.8				
4.5.64	3.9	1.0				
7.5.64	5.2	1.7				
14.5.64			28	12.5.64	72	
18.5.64	4.0	1.0				
21.5.64						
25.5.64	5.2	1.3				
29.5.64	10.4	2.6				
4.6.64	12.2	2.0				
15.6.64			30	11.6.64	88	
18.6.64						
25.6.64	46.7	4.7	15	26.6.64	70	purposed thirst at July and August to cause flowering at September
2.7.64	12.9	4.3				
6.7.64						
14.7.64	28.3	3.5				
28.7.64						
4.8.64	20.4	2.9				Second flowering
17.8.64						15.9
25.8.64	45.0	2.1	68	2.9.64	100	Picking 15/11
4.9.64			26	28.9.64	80	Weight of crop
22.9.64	66.8	3.7	27	25.10.64	80	1.5 tons/dunam



Crop : Peaches Var.: Ventura

Location : Nir Itzhak

Date of Planting : 1957

Extent of Orchard : 23 dunams

Depth of Sampling : 300 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
12.3.64						Foliation
19.3.64	13.6	1.9				1.3.64
9.4.64				23.3.64	90	
13.4.64	10.4	2.6				
24.4.64			23	15.4.64	30	
27.4.64			5	20.4.64	90	
4.5.64	29.7	4.2				
11.5.64			20	10.5.64	100	
14.5.64	12.7	4.2				
18.5.64						
21.5.64	28.0	4.0				
25.5.64	13.4	3.4				
28.5.64	11.3	3.8				
8.6.64			21	31.5.64	95	
11.6.64	13.5	4.5				
18.6.64			12	12.6.64	115	Picking
22.6.64	21.3	5.3				20/6 - 1/7
25.6.64	20.5	7.0				
6.7.64			20	2.7.64	90	Weight of crop
13.7.64	46.0	6.6				3,3 tons/dunam
21.7.64	55.0	6.8	21	23.7.64	120	
26.7.64	42.0	6.0				
26.8.64			18	10.8.64	120	Loss of foliage
23.9.64	140.0	5.0	20	30.8.64	120	15.10.64
19.10.64	90.0	3.5	26	25.9.64	120	
11.11.64			41	5.11.64	100	



Crop : Ground-nuts

**Location :** Nir Itzhak

Date of Planting : 12.4.64

Extent of Orchard 40 dunam.

**Depth of Sampling :** 150 cm

planted in rows of 5 x 60 cm



Crop : Alfalfa

Location : Nir Itzhak

Date of Planting : 1962

Extent of Orchard : 65 dunam

Depth of Sampling : 150 cm

Sampling Date	Moisture Deficit m <sup>3</sup> /dunam		Irrigation Intervals Days	Date of Irrigation	Amount given m <sup>3</sup> /dunam	Remarks		
	Total	Daily				Cutting Remarks	Yield kg/dunam	Date of cutting
12.3.64				25.2.64	60			
3.4.64	48.4	2.2	40	6.4.64	90	Hay	250	2.4.64
12.4.64								
22.4.64			11	17.4.64	72	Hay	280	25.4.64
29.4.64	37.0	5.3						
6.5.64			15	2.5.64	110			
13.5.64								
20.5.64	72.1	5.2	20	22.5.64	90		1000	21.5.64
27.5.64								
3.6.64			11	31.5.64	100			
14.6.64	68.5	6.2						
21.6.64			14	14.6.64	100		1500	17.6.64
24.6.64	70.0	7.0						
28.6.64			11	25.6.64	90			
5.7.64								
12.7.64	42.0	6.0	13	8.7.64	90		1500	15.7.64
19.7.64								
26.7.64	86.8	6.2		16.7.64	90			
2.8.64	40.0	5.7	15	23.7.64	90		1000	13.8.64
			10	2.8.64				
24.8.64			15	17.8.64	90			
3.9.64	163.0	5.4	14	1.9.64			1000	11.9.64
			14	15.9.64	90			
			16	30.9.64			1000	9.11.64
			15	15.10.64			1000	6.11.64



## CROP AND IRRIGATION DATA 1965

Location: Saad

Crop: Apples

Sampling Dates		Water consumption m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
		Total	Daily				
5. 4. 65	14. 4. 65	19.3	2.1				Foliation
14. 4. 65	22. 4. 65	16.0	2.0	18. 4. 65		6.0 rain	15. 4. 65
22. 4. 65	27. 4. 65	10.0	2.0	30. 4. 65		80	
10. 5. 65	17. 5. 65	26.2	3.7	20. 5. 64	20	80	
17. 5. 65	27. 5. 65	44.7	4.5				
27. 5. 65	1. 6. 65	23.7	4.7	5/6	17	85	
9. 6. 65	21. 6. 65	61.7	5.1				Date of gathering
29. 6. 65	13. 7. 65	84.7	6.0	25/6	20	80	20/8-20/9
20. 7. 65	27. 7. 65	30.9	4.4	17. 7	22	110	weight of crop
27. 7. 65	1. 8. 65	28.5	5.7	3/8	39	80	4 tons / dunam
10. 8. 65	22. 8. 65	66.9	5.6	27/8	24	130	
29. 8. 65	14. 9. 65	68.8	4.3				
14. 9. 65	21. 9. 65	26.1	3.7	15/9	19	120	
29. 9. 65	31. 10. 65	102.4	3.2	4/10		17.1 rain	
31. 10. 65	15. 11. 65	43.0	2.9			11.5 rain	loss of foliage from 15. 12. 65

Remarks: Efficiency of irrigation: 85%

Date of planting: 1953

Extent of orchard: 45 dunam

Depth of sampling: 300 cm



CROP AND IRRIGATION DATA 1965

Location: Saad

Crop: Grapes Var: Danug

Sampling Dates	Water consumption m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
5.4.65	14.4.65	23.1	2.6	18.4.65	60 rain	Foliation
24.4.65	27.4.65	11.0	3.7			5.5.65
10.5.65	17.5.65	17.2	2.5	3/5	50	
27.5.65	1.6.65	18.3	3.7	23/5	20	60
1.6.65	9.6.65	37.5	4.7			
9.6.65	14.6.65	15.0	3.0			
21.6.65	29.6.65	24.7	3.1			
20.7.65	25.7.65	17.7	3.3	5/7	43	100
25.7.65	3.8.65	30.9	3.4			
3.8.65	10.8.65	28.2	4.0	20/8	46	150
22.8.65	24.8.65	9.0	4.5			Weight of crop
29.8.65	7.9.65	49.2	5.5	10/9	21	60
12.9.65	21.9.65	29.0	3.2			1 ton/dunam harvest
21.10.65	31.10.65	36.0	3.6	25/9	15	115
9.11.65	15.11.65	14.4	2.4	4/10	17 rain	loss of foliage
				7/11	14.5 rain	from 10/11/65

Remarks: Efficiency of irrigation: 85%

Date of planting: 1956

Extent of orchard: 40 dunam

Depth of sampling: 300 cm



CROP AND IRRIGATION DATA 1965

Location: Saad

Crop: plums

Sampling Dates		Water consumption $m^3$ / dunam		Date of Irrigation	Irrigation Intervals days	Amount given $m^3/dunam$	Remarks of Plant Development
		Total	Daily				
5.4.65	14.4.65	41.0	4.6				
14.4.65	3.5.65	85.0	5.0	10.5.65		140	Foliation
17.5.65	1.6.65	86.0	5.7				20.3.65
14.6.65	29.6.65	79.5	5.3	10.6.65	31	90	
13.7.65	18.7.65	23.0	4.5				
20.7.65	3.8.65	56.0	4.0	8.7.65	28	175	
10.8.65	22.8.65	30.0	2.5				Picking
5.9.65	19.9.65	42.0	3.0	1.9.65	54	130	5-15/6
19.9.65	29.9.65	27.0	2.7				
21.10.65	31.10.65	20.7	2.1				Weight of crop
31.10.65	9.11.65	18.0	2.0				1.7 tons/dunam loss of foliage from 5.11.64

Remarks: Efficiency of irrigation: 85%

Date of planting: 1952

Extent of orchard: 56 dunam

Depth of sampling: 300 cm



CROP AND IRRIGATION DATA 1965

Location: Saad

Crop: Cotton Var. Acala 4-42

Sampling Dates	Water consumption $m^3$ / dunam		Date of Irrigation	Irrigation Intervals days	Amount given $m^3/dunam$	Remarks of Plant Development
	Total	Daily				
21.6.65	29.6.65	39.7	5.0			30.6.65
20.7.65	25.7.65	29.1	5.8	10.6	90	plants height 80 cm
3.8.65	10.8.65	42.9	6.1			" width 50 cm
15.8.65	24.8.65	45.3	5.0	6.7	26	flowering beginning
24.8.65	31.8.65	36.0	5.1			14.7.65
31.8.65	7.9.65	22.8	3.3	28.7	22	plants height 100 cm
7.9.65	12.9.65	24.3	4.9			25 flowers
12.9.65	19.9.65	17.9	2.5	12.8	15	per plant average weight of crop 4 tons/dunam

Remarks: Efficiency of irrigation: 90%  
 Date of planting: 12.4.65  
 Extent of field: 100 dunam  
 Depth of sampling: 150 cm



## CROP AND IRRIGATION DATA 1965

Location: Nir Yitzhak

Crop: Lemon Var: Jurica

Sampling Dates		Water consumption m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
		Total	Daily				
11.4.65	18.4.65	27.1	3.9	1-4/4		24.7 rain	
18.4.65	28.4.65	36.6	3.7	18/4		5.8 rain	
2.5.65	9.5.65	2.4					
24.5.65	30.5.65	19.2	3.2	12/5		110	
7.6.65	13.6.65	17.7	3.0	5/6	24	50	
4.7.65	11.7.65	23.1	3.3				
11.7.65	14.7.65	9.6	3.2				
18.7.65	21.7.65	9.3	3.1	16/7	41	100	
21.7.65	25.7.65	18.6	4.6				
28.7.65	1.8.65	21.6	5.4				
1.8.65	4.8.65	8.1	2.7				
4.8.65	18.8.65	39.9	2.8				
18.8.65	22.8.65	10.5	2.6	23/8	38	100	
29.8.65	1.9.65	11.7	3.9				
1.9.65	5.9.65	9.9	2.5				
8.9.65	15.9.65	17.1	2.4				
15.9.65	19.9.65	9.9	2.5				
5.9.65	8.9.65	6.6	2.2				

Remarks: Efficiency of irrigation: 85%

Date of planting: 1958

Extent of orchard: 36 dunam

Depth of sampling: 300 cm



CROP AND IRRIGATION DATA 1965

Location: Nir Yitzhak

Crop: Ground-nuts Var: Virginia

Sampling Dates		Water consumption m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Plant Width	Development Plant Height
		Total	Daily					
2.5.65	9.5.65	13.3	1.9	1.5.65		24		
10.5.65	23.5.65	30.0	2.3	10.5.65	9	15	9.4 cm	6 cm
24.5.65	13.6.65	52.0	2.7	20.5	10	10	14.0 cm	10
18.6.65	24.6.65	29.4	4.9	24.5	4	35	24.5	12
25.6.65	30.6.65	31.5	6.3	7.6	14	47	33.7	14 cm
1.7.65	7.7.65	37.8	6.3	18.6	11	43	51.4	24
8.7.65	14.7.65	40.8	6.8	25.6	7	29	60.0	35
15.7.65	4.8.65	152.0	7.6	1.7	7	26	"	40 cm
5.8.65	18.8.65	66.3	5.1	8.7	7	38	"	45
19.8.65	1.9.65	59.8	4.6	15.7	7	42	Date of	
9.9.65	15.9.65	25.2	4.2	22.7	7	50	Cropping:	26.9.65
				29.7	7	37		
				5.8	7	41	Weight of crop	
				12.8	7	41	450 kg / dunam	
				19.8	7	41		
				26.8	7	40		
				2.9	7	32		
				9.9	7	42		
				16.9	7	44		

Efficiency of irrigation: 85%

Date of planting: 2.5.65

Extent of field: 30 dunam

Depth of sampling: 180 cm



CROP AND IRRIGATION DATA 1965

Location: Nir Yitzhak

Crop: Peaches Var. ventura

Sampling Dates	Water consumption m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
	Total	Daily				
22.3.65	31.3.65	37.8	4.2	21-23/3	10.4 rain	Foliation
4.4.65	11.4.65	32.7	4.7	1-4 /4	24.7 rain	5.3.65
11.4.65	18.4.65	35.7	5.1	18/4	5.8 rain	
18.4.65	28.4.65	56.0	5.6	40/5	140	Picking
24.5.65	7.6.65	80.4	5.7			15.6-1.7
30.6.65	11.7.65	62.1	5.6	10/6	31	150
the orchard was destroyed because of Nenatod attack						
Remarks: Efficiency of irrigation: 85%	Date of planting: 1957	Extent of orchard: 23 dunam	Depth of sampling: 300 cm			



## CROP AND IRRIGATION DATA

Location: Nir Yitzhak

Crop: Grapes var: Alfons

Sampling Dates		Water consumption m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
		Total	Daily				
22.3.65	18.4.65	75.6	2.8	23.3-4.4		31.4 rain	
18.4.65	28.4.65	25.0	2.5	18.4		5.8 rain	Foliation
28.4.65	2.5.65	11.2	2.8	26.5		140	20.4.65
16.5.65	24.5.65	34.8	4.3				
30.5.65	13.6.65	85.3	5.4				
13.6.65	23.6.65	46.8	4.7	26.6	31	110	
30.6.65	11.2.65	41.4	3.8				
11.7.65	18.7.65	25.6	3.6				
18.7.65	25.7.65	22.5	3.2				Harvest
28.7.65	1.8.65	15.0	3.8	26.7	30	100	15.7-1.8
1.8.65	4.8.65	14.7	4.9				
4.8.65	18.8.65	61.5	4.4	30.8	35	120	
18.8.65	22.8.65	10.2	2.5				
22.8.65	25.8.65	8.4	2.8				
25.8.65	29.8.65	16.5	2.9				
1.9.65	5.9.65	12.6	3.1				
8.9.65	12.9.65	12.6	9.				
12.9.65	15.9.65	7.5	2.5				
15.9.65	19.9.65	12.9	3.2	27.9	28	120	Loss of foliage
							15.12.65

Remarks: Efficiency of irrigation: 85%

Date of planting: 1955

Extent of orchard: 58 dunam

Depth of sampling: 300 cm



CROP AND IRRIGATION DATA

Location: Kefar Hayarok

Crop: Oranges Var.: Shamouti

Sampling Dates		Water consumption m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
		Total	Daily				
7. 4. 65	15. 4. 65	21, 0	2, 6				
15. 4. 65	29. 4. 65	51, 8	3, 7	10. 6. 65		45	Flowering
13. 5. 65	21. 5. 65	22, 9	2, 9	6. 6. 65	27	60	15/3 - 15/4
10. 6. 65	22. 6. 65	12, 6	2, 1				
15. 7. 65	22. 7. 65	20, 7	3, 0	24. 6. 65	18	80	
22. 7. 65	2. 8. 65	34, 1	3, 1	13. 7. 65	19	80	
12. 8. 65	16. 8. 65	15, 6	3, 9	5. 8. 65	23	90	
16. 8. 65	23. 8. 65	27, 6	3, 9	24. 8. 65	19	90	
30. 8. 65	2. 9. 65	11, 7	3, 9	12. 9. 65	19	90	Picking
13. 9. 65	20. 9. 65	21, 9	3, 1				10. 1. 65
20. 9. 65	30. 9. 65	36, 3	3, 6	3. 10. 65	21	70	
19. 10. 65	29. 10. 65	37, 0	3, 7	1 - 19/10	rain	87, 8	Weight of crop 3 ton/dunam
29. 10. 65	7. 11. 65	21, 0	2, 3	23-25/10	rain	37, 0	
7. 11. 65	10. 11. 65	24, 0	2, 6	7/11	rain	15, 6	

Remarks: Efficiency of irrigation: 85%

Date of planting: 1957

Extent of orchard: 25 dunam

Depth of sampling: 300 cm



## CROP AND IRRIGATION DATA

Location: Kefar Hayarok

Crop: Grapefruit Var. Marsh



## CROP AND IRRIGATION DATA

Location: Kefar Hayrok

Crop: Grapes Var. Alfons

Sampling Dates	Water consumpt m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development	
	Total	Daily					
7.4.65	15.4.65	13.0	1.6				
15.4.65	29.4.65	33.4	2.8			Foliation 10.5.65	
7.5.65	13.5.65	13.0	2.2	15.5.65	60		
20.5.65	2.6.65	28.3	2.2				
2.6.65	15.6.65	42.3	3.2				
15.6.65	28.6.65	34.8	2.7	30.6.65	46	100	
19.7.65	2.8.65	63.3	4.5			harvest	
12.8.65	19.8.65	16.5	2.5	20.8.65	51	90	5-20/8
23.8.65	30.8.65	33.9	4.8				
6.9.65	16.9.65	41.7	4.2	6.9.65	17	80	Weight of crop
13.9.65	20.9.65	25.2	3.6	5-14.10	rain	87.8	2 tons/dunam
19.10.65	3.11.65	35.2	2.3	23-25.10	rain	37.0	loss of foliage
3.11.65	7.11.65	12.0	3.0	7.11	rain	15.6	5.12.65



## CROP AND IRRIGATION DATA 1965

Location: Kefar Hayarok

Crop: Apples Var. Grand Alexander

Sampling Dates		Water consumpt m <sup>3</sup> / dunam		Date of Irrigation	Irrigation Intervals days	Amount given m <sup>3</sup> /dunam	Remarks of Plant Development
		Total	Daily				
7.4.65	15.4.65	31.0	3.9	22.4		40	
7.5.65	13.5.65	16.7	2.8	14.5	22	60	Foliation
10.6.65	15.6.65	26.8	5.3	4.6	21	60	10.4.65
12.7.65	15.7.65	15.0	5.0				
15.7.65	22.7.65	32.4	4.6	28.6	24	70	
12.8.65	16.8.65	14.1	3.5	16.7	18	60	Picking
23.8.65	30.8.65	22.2	3.2	1.8	16	60	15.7-30.7
30.8.65	6.9.65	25.8	3.7	26.8	19	70	
13.9.65	16.9.65	6.9	2.3	10.9	21	60	Weight of crop
20.9.65	19.10.65	93.6	2.4				
19.10.65	28.10.65	23.0	2.5	5-14/10	rain	87.8	3 tons/dunam
3.11.65	7.11.65	30.6	3.0	23-25/10	rain	37.0	loss of foliage
7.11.65	16.11.65	24.6	2.5	7.11	rain	15.6	5.12.65
Remarks: Efficiency of irrigation: 85%							
Date of planting: 1957							
Extent of orchard: 12 dunams							
Depth of sampling: 300 cm							



## CROP AND IRRIGATION DATA

Location: Kefar Hayarok

Crop: Plums Var. Ogden



## VOLUME III. LITERATURE REVIEW AND BIBLIOGRAPHY

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## LITERATURE REVIEW

The literature dealing with evapotranspiration and evaporation is extensive, and many publications have appeared in the last 50 years. An attempt has been made in this brief review to describe the major problems investigated by scientists during the period mentioned.

### Factors Affecting Evapotranspiration

Evapotranspiration is a term expressing the combination of evaporation and transpiration. Evaporation is a process by which water is transferred to vapor by the absorption of heat energy, while transpiration is a process whereby water vapor is dispersed through the stomata of plant leaves. Thus, evapotranspiration is defined as the total loss per unit area of water used by the plant in transpiration and that transferred from the soil to the atmosphere by evaporation.

Three main factors affect the plant's ability to produce yields: 1. inherited characteristics, 2. soil factors, and 3. climate. The effect of each of these main factors is clearly manifested in evapotranspiration, which, together with photosynthesis, represent the two most important processes in the plant world. The influence of climate on evapotranspiration is of major importance, although as already indicated, it is not the only factor affecting these processes. Additional factors on which evapotranspiration depends include the specific crop, climate, soil moisture, salinity, degree of plant cover, and many others which will not be considered here. Investigators consider climate to be the most important factor affecting water consumption, while next in importance come the water supply, the soil, and the topography,

#### A. Effect of Climate on Evapotranspiration

Two basic physical systems are recognized as regulating the climate in close proximity to the plant: 1. the energy balance, and 2. aerodynamic transfer phenomena. Both of these systems can be sub-divided to include solar radiation, precipitation, temperature, hours of sunlight, humidity, wind velocity (or daily wind distance), and growing season. Many of these factors are interrelated, and



it is difficult to define the specific effect of each of them on evapotranspiration. It is possible to separate schematically those factors related to the energy balance which are required for the evapotranspiration process, from those factors related to the aerodynamic transfer phenomena.

#### Factors related to the energy balance

On the assumption that of the group of climatic factors influencing the energy balance, the main source of energy is the sun's rays reaching the earth surface, it is possible to represent the radiation absorbed by the plant surface by the following energy balance equation:

$$R_N = R_I (1 - r) - R_B$$

where  $R_N$  = the amount of radiation absorbed by the plant surface

$R_I$  = short-wave radiation from the sun, atmosphere, and clouds

$r$  = portion of short-wave radiation reflected by the plant surface

$R_B$  = long-wave (heat) radiation reflected by the plant surface.

The actual quality of heat exchange depends on the vertical temperature gradient. That is, if the plant is warmer than the air it will lose heat to the air. On the other hand, a cold plant will absorb heat from the air. It has been found (17) that during a 24-hour period more energy was taken from the atmosphere than was returned to it. It has also been shown (41) that the vertical energy balance can be used to give a good estimate of evapotranspiration on an hourly or half-hour basis.

#### Effect of temperature

Certain researchers relate the effect of temperature to the general rate of biological processes. Since it is known that transpiration is a process controlled biologically, it is therefore also affected by the two basic laws acting on the plant under the influence of temperature: 1. Hopkin's Bioclimatic Law which states that for every degree North latitude, or rise in elevation of 400 ft, there is a 4-day



lag in blossoming. 2. Van't Hoff-Arrhenius Law stating that in the vicinity of the specific optimum temperature of a plant, an increase of  $10^{\circ}\text{C}$  will double the rate of biological processes. The formal law is generally expressed as  $Q_{10} = 2$ , where  $Q_{10}$  represents a rise of  $10^{\circ}\text{C}$ , and the digit 2 represents a doubling of the rate of a biological process. Of course this is only a narrow aspect of the temperature effect, and in general it is difficult to separate the factor from the broader influence of the energy balance.

#### Effect of relative humidity

The relative humidity is also influenced by the general energy balance in the plant vicinity, and many investigators are attempting to reach a qualitative evaluation of evapotranspiration based on the vapor pressure gradient. Dalton (9) found, 150 years ago, that water vapor transfer depends partly on the vapor pressure gradient, that is, the difference between the vapor content of free air above the crop and the vapor content on the evaporating surface. From this it is clear that on a day when the free air above the crop has a low relative humidity (the ratio between the vapor pressure of the air and the maximum possible pressure at the given temperature is low) the values of evaporation and evapotranspiration will be high, while on a day with a high relative humidity, the vapor pressure will be lowered and the values for the above processes will be low.

#### Effect of day length

Many researchers relate day length to geographical latitude. North of the Equator, summer days are longer than at the Equator due to the earth's tilted axis and its movement. And since the sun is the source of all the energy used by growing plants and by evaporating water, the longer day permits a longer period for evapotranspiration.

#### Aerodynamic transfer processes

Workers who emphasize the importance of the energy balance in evapotranspiration processes state that heat exchange depends not only on a vertical temperature gradient, but also on aerodynamic transfer processes. Heat transfer from the evaporating surface is brought about by turbulence or convection.



The turbulence is created by winds above the plant cover. The higher the wind speed or the greater the daily wind distance, the more efficient is the turbulent heat exchange, and the greater is the degree of heat exchange (or energy) between the evaporating surface and the free air.

#### The effect of soil factors and water supply on evapotranspiration processes

In studying the effect of soil factors and water supply on evapotranspiration, the following are considered important: the availability of soil water in the root zone as a factor on which the transpiration rate depends, the water quality, and soil fertility. Also sometimes included are the effect of irrigation technique and the amount of precipitation (which is actually also a climatic factor). Soil moisture in the root zone is a main factor influencing the amount of water available to the plant, and this factor is related to rainfall, irrigation, and water held by the soil. In locations with an abundant and cheap water supply there is a tendency to over-irrigate, and when the soil surface is frequently wet, evaporation is high and the combination evaporation-transpiration (which is actually consumptive water use) reaches high values. In the case of irrigation by flooding, a large amount of water evaporates before it succeeds in reaching the root zone. When the water surface is close to the soil surface, the values obtained for evaporation are almost the same as those for evaporation from free water surface. As the ground water drops to a greater depth, there is a decrease in the evaporation in relation to evaporation from a free water surface, until a certain soil depth is reached whereupon the capillary channels are unable to raise the water to the soil surface and the evaporation value can be disregarded.

#### The effect of soil moisture stress

A number of factors effect the soil moisture stress such as soil type, salinity of the water in the pores, and the total water content.

Regarding the actual transpiration resulting from an increasing soil moisture stress, there is a divergency of opinion. The classic theory of Veihmeyer (46), Veihmeyer and Hendrickson (47) and others states that soil moisture is not a



factor limiting actual transpiration in the range between Field Capacity and Wilting Percentage. Lemon, et al (17) have shown in their experiments that when soil moisture stress was 15 atm (a stress closely approximating that existing at Wilting Percentage), the evapotranspiration of cotton was zero, and for lower stress values, the evapotranspiration was about 1.25 mm/h. Their results indicated a gradual increase in the amount of water lost by evapotranspiration in accordance with amounts of irrigation water applied. As the application increased, the evapotranspiration values were greater. From the point of view of energy balance, it was found that all the net radiation received by the evaporating surface returned to the air as heat flow in the case that no water was transferred to the air through evapotranspiration.

If it is necessary to increase the water application for leaching salts, there will be a greater total water loss from evaporation and transpiration, even if the transpiration decreases somewhat.

#### The effect of irrigation method on evapotranspiration level

It has already been mentioned that if fields are flood-irrigated much water is lost by evaporation before it succeeds in penetrating the entire main root zone. Rainfall and sprinkler irrigation have a similar effect insofar as water penetration is concerned: part of the water evaporates before it reaches the full depths of the root zone and is thus not utilized for transpiration. The amounts of water supplied to the plant also has an effect on the consumptive use, and this is expressed (in addition to factors already mentioned, as the tendency to waste water in those places where it is abundant and cheap) also on the yield level. As a result of high evapotranspiration rate, within certain limits a large water application will increase yields while amounts smaller than required will reduce the yield. Every factor responsible for increasing yields .Every factor responsible for increasing yield indirectly brings about an increased consumptive water use. The area of the evaporating surface increases with the growth of foliage, as does the amount of water lost by transpiration. Similarly, within the optimum range there is a decrease in the water requirement per unit of yield. As in the case of all factors



responsible for raising yields, fertile soil has the effect of increasing consumptive water use. Various agrotechnical practices such as cultivation, fertilization, plant protection against diseases and insects, and others have a like effect on water use.

The effect of the specific crop on evapotranspiration

The physical mechanism is not the only process governing the transfer of water vapor from the soil and the plant to the atmosphere. There is also a biological mechanism which helps regulate transpiration. The transpiration rate depends on the degree of plant development, the amount of foliage, and the nature of the leaf surface.

The amount of radiation absorbed by the plant surface can be described by an equation which characterizes the plant's energy balance, and  $R_N$  as previously defined, is incorporated in the equation as follows:

$$R_N = E + K + S + G$$

where  $E$  = the energy exploited by latent heat of evaporation (540 calories are required in order to change  $1\text{ cm}^3$  of water to vapor)

$S$  = the heat exchange between the plants and the soil by conductivity

$K$  = the heat exchange from the plant surface to the surrounding atmosphere by convection

$G$  = the energy used for photosynthesis and stored as dry matter

The terms  $E$  and  $G$  can be considered as variables dependent on the specific crop. Thus, for example, the photosynthetic efficiency of evergreen trees is lower than that of deciduous trees. The energy used for photosynthesis by evergreens is less than that used by deciduous trees, and is released for other processes. Israelson and Hansen (16) mention the possible existence of competition over the sources of energy. Energy used for evaporation of water from the soil is not available to the plant. Raindrops remaining on the leaves exploit the energy, and the transpiration rate consequently decreases. The same authors also showed that the evapotranspiration rate increases until it reaches a peak at plant maturity,



after which it drops. The peak occurs at the beginning of flowering, after the vegetative growth period has ended. Lemon, et al (17) describe a similar situation for cotton. They found that the fluctuations in relative water loss are determined by soil moisture and physiological factors, while the general form of the evaporation vs. time curves is determined by meteorological factors.

Regarding the nature of the leaf surface, it is important to mention that its ability to absorb the energy of the sun's rays is determined to a certain degree by the leaf's angle in relation to the rays. In the event that the rays hit the leaf perpendicularly, there will be maximum absorption, while if the rays are parallel to the leaf surface, there will be minimum absorption. Naturally, there are intermediate conditions as well. Varying external conditions cause fluctuations and diurnal changes in stomatal transpiration by means of internal regulating mechanisms. It has been found (5, 11, 30) that transpiration reaches a temporary minimum when the relative humidity of the air is extremely low, or when the plant's saturation deficit reaches maximum values during the hot hours of noon.

### Summary

The soil, plant and atmosphere together constitute one system in the transfer of water from the soil and the plant to the atmosphere. In the present review, attention has been paid to the most important individual influences of each of the factors mentioned, all three of which together are responsible for evapotranspiration. The conclusions of this review are as follows:

1. Meteorological factors should not be considered to the exclusion of the others
2. Soil moisture stress is not the only factor governing water loss.
3. The plant acts both directly and indirectly in regulating water transport.

In the light of these conclusions, we shall now review the various approaches and techniques in calculating and measuring evapotranspiration.



#### Methods of Determining Water Loss by Evaporation and Evapotranspiration

A number of methods (15) are known for estimating the loss of water from the soil by evaporation and evapotranspiration. At the beginning of this review evapotranspiration was defined as a combination of evaporation and transpiration, where evaporation is a process by which water is transformed to vapor through the absorption of heat energy, while transpiration is a process whereby water passes as vapor through the stomata of the plant leaves.

More exact definitions of the phenomena will include:

- a. Actual evapotranspiration: the total water loss per unit area for the entire growing period of the crop.
- b. Potential evapotranspiration: the upper limit of actual evapotranspiration, obtained when soil moisture is unlimited and there is complete plant cover during the vegetative growth period. (Under such conditions, factors as soil permeability and water retention properties are disregarded).
- c. Pan evaporation: the measurement of evaporation from a standard United Weather Bureau Class A evaporation pan.

These forms of estimating water loss, their interrelations, and methods of calculation comprise the next section of this review.

#### The Relation Between Evaporation and Evapotranspiration

Many workers have established that there is a close relation between evaporation from a Class A pan and the evapotranspiration of various crops. In general, the attempt was to arrive at the following relation:

$$E_t = a + b E_o$$

Where  $E_t$  = potential or actual evapotranspiration

$E_o$  = evaporation from a pan or a free water surface

b = a correction factor

a = a constant



Stanhill (35) found such linear relations in Israel for various crops during the irrigation season. The equations which he derived to describe these relations are summarized in the following table:

Year	Crop	Location	Equation ( $E = \text{mm}$ )	Yield, Kg/dunam
1959	Acala	Cotton Gilat	$E_t = 0.83E_o - 260$	387
1960	"	" "	$E_t = 0.71E_o - 230$	373
1959	"	" Beit Shean	$E_t = 0.60E_o - 260$	420
1959	Pima	" " "	$E_t = 0.62E_o - 220$	370
1960	Corn	Gilat	$E_t = 0.72E_o - 200$	771
1959	Peanuts	Beit Dagan	$E_t = 0.56E_o - 70$	540
1959	Sorghum	Gilat	$E_t = 0.88E_o - 210$	825
1961	Grapes	Even Sapir	$E_t = 0.58E_o - 180$	2770
1960/61	Agave	Gilat	$E_t = 0.22E_o$	134

All cases, except the last two refer to annual crops having a limited irrigation season, and thus deviations were observed from the straight lines of the equations, due to the effect of the season of the year. Deviations were apparent for the months of April-May, while in most cases a linear correlation was obtained for the months of June, July, August, and even September.

A linear relation between evapotranspiration and evaporation can be expected only in the case of ever-green crops which cover the ground completely or to a constant degree. This can be seen in the results obtained for Agave.

Fuchs and Stanhill (12) examined the ratio between consumptive water use by cotton and pan evaporation in order to develop meteorological indicators for irrigation. The sigmoidal form of the curve for evapotranspiration vs. pan evaporation for various crops, and especially for cotton, as obtained by Stanhill (35), was only partly confirmed by these experiments because the observations were not begun early enough in the season. But here also there was an almost linear relation between cotton evapotranspiration and pan evaporation. The differences in slope



of the curves was due primarily to the irrigation regime and evaporation conditions. At an optimum irrigation regime the slopes depend only on evaporation conditions. These can be calculated by means of the pan data.

The above authors, in their work with non-irrigated cotton (13) found that the average slope was 0.70, the average standard deviation was 0.19, and that there was a non-significant trend towards a reduced slope as the evaporation intensity grew.

Lomas (19) found at Lod and at Gilat a high linear correlation between a Thornthwaite lysimeter located in a mixed clover-alfalfa field (see section on direct methods of measurement) and a Class A evaporation pan. The equation expressing the relation between the two parameters as given by Lomas is as follows:

$$E_L = 1.06 E_A - 0.7$$

Where  $E_L$  = evaporation from Thornthwaite lysimeter ( $= E_t$ )

$E_A$  = evaporation from Class A pan ( $= E_o$ )

The values 1.06 and 0.7 correspond to the symbols a and b, respectively.

No seasonal fluctuations were observed in the ratio between pan evaporation and potential evapotranspiration as measured in the lysimeter. This supports the theory that the climatic factors involved (radiation, temperature, relative humidity, and wind speed) have a similar effect on both systems.

Penman and Schofield (27) found that the ratio between evapotranspiration and evaporation ( $E_t/E_o$ ) changes with the season. Penman's approach for calculating  $E_t$  is different than those mentioned above, and a special section will be devoted to a general discussion of it. Penman estimates evaporation from the soil by the use of instruments to measure the physical processes taking place in the soil as affected by climatic factors. Denmead and Shaw (10), working with corn in Iowa, reported that the ration  $E_t/E_o$  changes with the growing season. Their results are summarized in Figure 1.



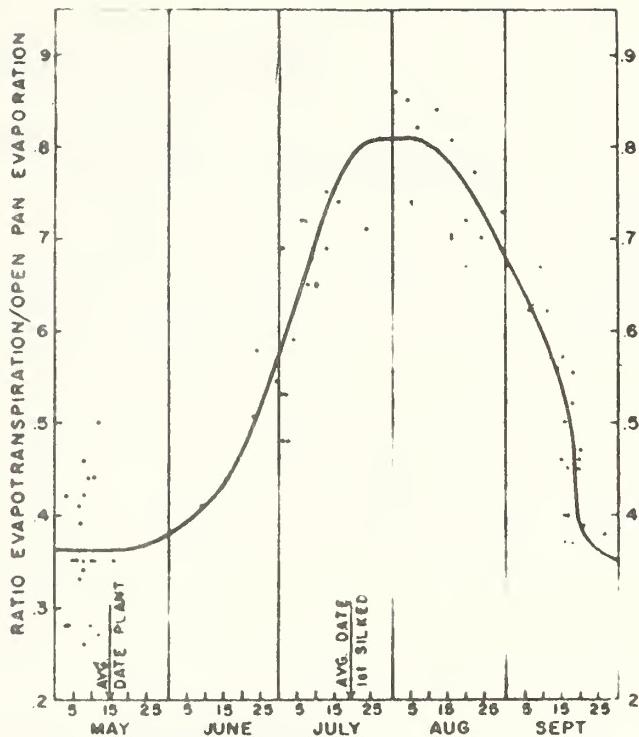


Figure 1--The ratio of evapotranspiration from corn to open-pan evaporation throughout the growing season.

During the months April and May the ratio was 0.36, but there was much variability in the results for this period. This is attributed to factors such as seeding date which was different between locations and years, preparation of the seed-bed which was non-uniform during the growing period and between the different experimental locations, and to some extent the effect of runoff.

In July and August there was a period of 16 days during silking when the  $E_t/E_o$  ratio reached 0.81, after a rapid rise. During this period, the ratio grows with the leaf area, the plant is green and actively growing, and there is maximum ground cover. At the end of the growing season there is a reduction in the ratio which is initially gradual following the gradual decrease in area of living leaves, but subsequently becomes rapid due to the termination of any physiological activity by the plant.



Similar results were obtained by Stanhill (36) who arrived at an average ratio of 0.85 in Israel.

#### Methods of Determining Evapotranspiration

##### A. Direct Methods of Determining Evapotranspiration

There are various direct methods of determining the amounts of water lost by evaporation from a pan, and by potential and actual evapotranspiration. They are primarily based on measuring changes in soil moisture content, and changes in plant and soil weight. The main methods are:

- I. Measurement of changes in soil moisture.
- II. Measurement of changes in weight of tanks and lysimeters.
- III. Field plot experiments.
- IV. Integration method.
- V. Inflow-outflow method for large areas.

##### I. Measurement of changes in soil moisture

Many field experiments conducted with plants require the periodic determination of soil water content or moisture tension. Such determinations are of paramount importance to the farmer if he is to exercise close control over the quantities of water applied in intensive agriculture. The simpler and cheaper the method, the more widely it will be used, especially by the farmer. This section will describe a number of the most commonly-used methods for making these measurements.

(a) Gravimetric method. Changes in soil moisture content may be measured by means of various types of boring instruments. One example is the Veihmeyer soil tube which removes cores 1" in diameter. The soil sample is dried in a standard manner ( $105^{\circ}\text{C}$  for 24 h) and the percentage moisture on a dry weight basis is computed. Richards (32) recommends this method to farmers when they are familiar with the soil and its specific properties. Only under such conditions can he compare the results obtained with the moisture percentage at wilting point, and thus determine



the time of irrigation. West and Perkman (51) used a Veihmeyer tube to remove soil samples from a depth of 4-12" (this represents 60% of the root zone of citrus trees in the study). They took 4 samples from each plot of 10 ft<sup>2</sup> in order to define accurately the soil moisture at the specified depth. From this brief description of their work it is possible to detect a number of outstanding deficiencies of the method which have been pointed out also by other workers (21, 32):

1. Much labor is required to obtain a large enough sample to guarantee sufficient accuracy. This is a major problem in research experiments.
2. The method of boring necessitates sampling each time in a new location, and even if the second sample is taken in close proximity to the first, the results may be influenced by soil variability and moisture content, even after an irrigation.
3. The work is difficult and unpleasant.
4. Stoney or gravelly soil cannot be sampled.
5. The measurement gives the moisture content by weight, and difficulties in determining the soil's apparent density results in inaccuracies when converting the moisture content from a weight to a volume basis.
6. One must wait at least 24 h until the soil samples are sufficiently dry to complete the determination.

(b) In situ determinations of undisturbed soil.

1. Measurement of moisture content by following changes in electrical resistance.

Bouyoucos and Mick developed a gypsum block which came into wide use for measuring soil moisture in the field. By this method changes are measured in the resistance of a porous body (e.g. gypsum, fiberglass, and nylon in various forms) to the passage of an electric current. Any change in the moisture content of the soil brings about a similar change in the clock. An increase in moisture content reduces the electrical resistance between two electrodes located in the block, and vice versa.

The block must be able to withstand soil conditions for extended periods of time, it



must be sensitive to moisture changes within the available moisture range, and it must be adaptable to all soil types (6, 29). The disadvantages of the method are:

1. The high solubility of gypsum results in a buffering effect, and the sensitivity to change drops (nylon and fiberglass units are highly sensitive to the effect of the solution).
2. The block is not sensitive in very wet soils.
3. The unit has a limited period of use.
4. Calibration is required. This can be done by directly translating the moisture content by weight obtained by gravimetric or tension measurements. Calibration curves of resistance as a function of moisture tension are obtained by means of pressure membranes, but these curves can change with time (21).
5. There is a hysteresis effect whereby the calibration curves obtained for drying and wetting are different (42).

In comparison to the gravimetric method, this measurement is much easier to carry out. Compared to the use of tensiometers, blocks can be utilized in dried soils (32) (this is of value in soils with a limited water supply, or in the case of grain crops which do not require much irrigation during the ripening period), and the cost per instrument is lower.

2. Measurement of moisture content by means of soil water tension. The tensiometer is the only instrument suitable for measuring water tension (21). It consists of a porous ceramic cup buried in the soil and connected by means of a water-filled tube to a manometer. As the soil moisture tension causes a drop in the height of the water column within the tube, a vacuum is created which can be measured with the manometer.

Richards, one of those most responsible for developing the instrument, and Richards and Marsh (31) have presented suggestions for timing irrigations by using tensiometers. They specify its special suitability for irrigating large areas of crops such as citrus, potatoes, vegetables, and woods (32). Tensiometers are widely used, especially in soils with a high water-retention capacity.



Characteristics of the tensiometer:

- a. It is suitable for tensions less than 0.85 atm which is the air-entry value of the instrument. (Theoretically, the pores of the ceramic cup are small enough not to permit air passage when a tension of 1 atm is applied to the water in the pores (21)).
- b. When the water in the instrument is under a tension greater than one atm it begins to boil, air bubbles enter the water column, and it is necessary to refill the instrument.
- c. It is affected by temperature change. If there is a temperature gradient from the crop to the soil, there is vapor movement towards the soil and this affects the moisture tension being measured. Furthermore, temperature changes are manifested by the height of the water column because of the tube's small diameter. This also affects the measured tension.
- d. It cannot be used in all soils. In sandy soil one can obtain information on water status within the range of 50-75% available water. On the other hand, in the case of clay soils which retain much water at tensions greater than 0.85 atm, the instrument is of limited value.
- e. The readings are affected by hysteresis (33), and a large number of determinations are required to avoid large statistical errors.
- f. Calibration by the gravimetric method is required, and thus the soil moisture is expressed on a weight basis.
- g. Contact between the cup and the soil is not always satisfactory, and it may take a long time until the instrument begins to respond to changes in soil moisture.
- h. It is necessary to refill the tensiometer if the soil becomes too dry.



3. Neutron scattering. The method was developed when the need arose to follow soil moisture changes without disturbing the sample, and serves to measure the cumulative changes in soil moisture at a given location.

The instrument is composed of three main parts (15): a source of fast neutrons, a receiver of slow neutrons, and a scaler. The source of the fast neutrons is a mixture of Radium and Beryllium emitting gamma-rays, or Americium emitting neutrons which are freely scattered throughout the soil in all directions. In their path they collide with nuclei of different atoms in the soil and gradually lose their kinetic energy. The maximum loss of energy occurs when the neutron collides with nuclei having a mass similar to its own, such as hydrogen nuclei found in water. Thus, it is clear that the slowing-down of fast neutrons is proportional to the soil water content. The slow, or thermal neutrons as they are called, continue their random movement, part of them returning to the radioactive source beside which is located an absorber of slow neutrons. Each thermal neutron entering the absorber causes an electric pulse which is registered by the scaler. Since most of the hydrogen nuclei in the soil are part of the soil water, it is possible to express the moisture content on a volume basis in terms of number of counts per minute (cpm).

Characteristics of the instrument:

- a. It is possible to select a number of permanent measuring locations as needed. The method is especially suited for those situations where it is desired to measure changes in moisture content with time, at the same location (37).
- b. Changes close to the soil surface cannot be measured due to the loss of neutrons to the air.
- c. A calibration curve is needed based on gravimetric measurements.
- d. The instrument's high cost makes it inaccessible to farmers for day-to-day use.
- e. Results are affected by high organic matter content (because of the many hydrogen atoms), by the presence of B, Cl and Fe, and by the crystal lattice of water(21).



f. Ease and rapidity of operation (32).

4. Methods based on changes in heat conductivity of the soil as a function of moisture content. These methods (48, 49) and others not mentioned are not sufficiently developed (32), and they are used mainly in research work. The heat conductivity of the soil generally increases with moisture content (15), and changes in the rate of temperature increase at a certain point in the soil result in changes in the flow intensity of electric current in a thermocouple (48). These changes are measured with a galvanometer at different times, and if the ratio of the galvanometer change to the thermal conductivity of the soil is known, it can be translated from terms of temperature to terms of moisture content.

Characteristics of the method:

- a. It is free from the effect of salts, as compared to the situation regarding gypsum blocks (21).
- b. It is not successful in certain soil types due to poor contact.
- c. Calibration is required for each specific soil.

II. Measurement of changes in soil and plant weight by means of tanks and lysimeters

Israelson and Hansen (16) described a lysimeter to which the water is supplied by means of a Mariotte system. In general, experiments with tanks and lysimeters are based on an attempt to artificially create a situation duplicating natural field conditions. Such studies are limited by the amount of soil that can be used, by the size of the tank, by arrangements for supplying water, and occasionally by the difficulties encountered in creating different environmental conditions.

Methods of use. The tanks should be so located in the field that the consumptive water use of the plants in the tank will be the same as that of the



surrounding vegetation. Water is supplied by a Mariotte system in sufficient quantity to maintain a constant amount in the lysimeter. The amount of water lost by evapotranspiration can be found by calculating the difference (daily or weekly) between consecutive measurements. Lomas (19) used a Thornthwaite lysimeter. McMillan and Paul (20) suggest a different method for measuring changes in the weight of large soil masses by using Archimedes' principle of floating bodies to build a floating lysimeter. Van Bavel and Meyers (45) propose automatic methods for weighing and electronic systems for recording.

The above examples are only a few of many types of lysimeters. A complete listing is not within the realm of the present review.

**III. Field plot experiments.** Israelson and Hansen (16) describe the work of Widtsoe who measured the amounts of water that 14 crops consumed during their growing period. The study lasted 10 years, from 1902 to 1911. The yields produced by each crop are presented on a curve as a function of the amounts of water applied. In most cases there was a rapid increase in yield with the water applied, until a certain point was reached when additional water applications resulted in a reduced yield or a very low yield increase. This change was expressed by a break in the curve. The amount of water required for growth at the break in the curve is the consumptive water use for the specific crop. In his work, the author emphasized the importance of the yield in defining consumptive water use, thus incorporating economic aspects related to the law of diminishing marginal output. Attention should be paid to the fact that Widtsoe disregarded the water loss caused by deep percolation, considering this water as though it had been exploited by the plant. Thus, the values obtained in his work are relatively high.

**IV. Integration method**

This method has also been described by Israelson and Hansen (16). According to this method, the consumptive water use of the plant is equal to the total production from one unit of consumptive use multiplied by the area of the crop, plus one unit of consumptive use by weeds multiplied by the area of weeds,



plus evaporation from a free water surface multiplied by the area of the surface,  
plus evaporation of non-cultivated land multiplied by its area.

Clearly, the major disadvantage of the method is the difficulty in gathering the basic information mentioned such as areas, units of consumptive water use by the crop, etc. From this it is also clear that the method was used only for large areas where the consumptive use per unit yield was already known. Such is not the case for new areas where specific experiments have not been conducted, and it is therefore difficult to consider this method as significant in determining the consumptive water use of a crop.

#### V. Inflow-outflow method for large areas

This method (16) uses the following equation:

$$U = (I + P) + (G_s - G_e) - R$$

where  $U$  = the total consumptive water use of the field or the valley

$I$  = the amount of water flowing to the valley during the 12 months of the year (inflow)

$P$  = total annual rainfall (in mm) x the given area

$G_s$  = water stored in the soil at the beginning of the year

$G_e$  = water stored in the soil at the end of the year

$R$  = annual flow out of the area under consideration (outflow)

Notes: All the volumes are measured in the same units. The value  $(G_s - G_e)$  is arrived at by measuring the differences in the height of the water table during the period studied.

The average consumptive use per unit area is obtained by the fraction  $U/S$ , where  $S$  = the given area.

The estimation of evaporation and evapotranspiration from equations or formulas.

Direct methods of determining evapotranspiration as described in the previous section are expensive and difficult to carry out. Their specific disadvan-



tages were also enumerated. Quite naturally, a search has been conducted for a suitable formula which can replace the direct methods of measurement. Such a formula can be based, in general, on the degree of evaporation, which is an easy parameter to determine, or on data obtained from standard meteorological stations. It is necessary to know the correlation between climatic conditions and the degree of evaporation at the same location.

The formulas can be divided into three main categories:

- a. Theoretical methods based on the physics of vapor movement.
- b. Theoretical methods based on the energy balance.
- c. Empirical methods based on temperature, radiation, relative humidity, and other meteorological parameters.

a. Theoretical methods based on the physics of vapor movement. Evapotranspiration is a process in which water vapor from the plant is transferred to the atmosphere. Thus, the flow of water vapor is a function of the vapor pressure gradient. As long as the vapor pressure of the air is lower than the vapor pressure of the wet soil-plant complex, there will be a movement of vapor from the complex to the air. If no factor exists to carry the water vapor from the evaporating surface, the air in contact with this surface will have a vapor pressure at saturation and will be in equilibrium with the evaporating surface. At this point the evaporation process will cease. This is the basis of the aerodynamic method by which evaporation is calculated according to the degree of movement of the evaporated vapor from the plant's surface. This approach to evaporation incorporates a number of complicated problems of microclimatology, and demands an understanding of hydro- and aerodynamic processes.

In this method, the location where the variables are measured is important since it can be assumed that the evaporating water moves not only upwards but also to the sides. The wind is of major importance in directing vapor



movement. The horizontal movement of water vapor by wind is called eduction. The study of evapotranspiration by eduction must be done on level surfaces free of any obstruction to vapor movement. The condition of the evaporating surface, its texture, and its thermal properties have a great influence on the movement and flow of air. Also, the transfer of air from a cultivated and irrigated surface to bare or dry areas brings about new microclimatological conditions. After the air reaches equilibrium with the new surface an internal atmospheric boundary layer will be formed. Under this layer, the microclimate will represent the new surface conditions, while above the layer will exist the climate of the area from which the wind originated.

The height of the layer is of practical importance. Each aerodynamic measurement must be made on a layer representing the surface in which we are interested. Since most of the measurements made to determine evapotranspiration are gradients, there is a need for a certain depth, and if the exposed area is not long enough, there is a danger of measuring the condition of the surface from which the wind came, and not of the surface in which we are interested.

In the air layer close to the plant it is possible to detect 2 layers of major importance to vapor movement: the surface layer and the laminar layer. The thickness of the laminar layer is minimal, and water vapor movement through it takes place by molecular diffusion. The transfer of air through the layer is affected by wind speed and the nature of the matter composing the surface. The movement is always laminar and horizontal.

Within the surface layer found above the laminar layer, air and vapor flow is turbulent. Air flow in this layer is affected by the roughness of the surface and the temperature. The efficiency of water vapor transfer through the laminar layer is very small in comparison to the other layers wherein air movement is turbulent. Thus, the laminar layer represents a "bottle-neck" to vapor movement.



The flow equation for vapor diffusion through this layer is analogous to the heat flow in soil, and according to Fick's Law, it can be written as follows:

$$E = \frac{D(q_2 - q_1)}{L}$$

where  $E$  = flow of water vapor in volume per unit area per unit time

$q$  = concentration of water vapor at the upper end,  $q_1$ , and at the lower end,  $q_2$ , of the laminar flow; that is, on the evaporating surface and at the upper boundary of the laminar layer

$D$  = diffusivity constant

$L$  = the diffusion path in units of length

Dalton's equation (9) for determining evaporation as presented about 150 years ago,  $E = f_u (e_s - e_a)$ , is actually very similar to the above equation, where  $f_u$ , a function of the wind, takes the place of the resistance component,  $D \times 1/L$ . But since the laminar layer is so thin, there is no possibility of measuring the water concentration nor the wind speed at the upper boundary of this layer.

The diffusivity constant,  $D$ , must be measured at a certain spot distant from the evaporating surface and which is in a layer of turbulent flow where diffusion does not take place by molecular transfer. Therefore, the coefficient in Dalton's equation can only be found empirically.

Nevertheless, Dalton's equation, also known as the mass transfer equation, is the most widely used in the aerodynamic method, particularly in measuring evaporation from a water surface. On the water surface, the vapor pressure,  $e_s$ , can readily be determined from the temperature of the water's surface;  $e_a$  and  $u$  are measured at a certain point above the surface. To determine  $f$ , many studies have been conducted. One of these is the basic work done at Lake Hefner, Oklahoma, where it was found that  $E = 1,214 \times 10^{-3} U_q (e_s - e_q)$



where  $E =$  evaporation in  $\text{cm}^3/\text{h}$

$U_q =$  wind speed at a height of 8 m, in  $\text{m/sec}$

$e_q$  and  $e_s =$  vapor pressure at the surface and at a height of 8 m,  
respectively, in mg.

Similar studies were conducted at Lake Mead, Nevada, as well as by Australians and Russians who found a transfer coefficient resembling that of Lake Hefner,  $1.3 \times 10^{-3}$ .

If one is interested in determining evapotranspiration by means of mass transfer, the coefficient will be still more empirical since there exists here an additional resistance to that of the laminar layer -- the stomata.

A number of methods have been proposed to calculate empirically the mass transfer coefficient of a specific crop or of a plant at different stages of growth or in different ecological environments. All are based on the equation

$$fu = \frac{e_s - e_a}{E_t \text{ measured}}$$

All the methods assumed that the evaporating surface is completely saturated, and were therefore concerned solely with the measurement or calculation of the surface temperature. All the methods require the measurement of at least the wind and relative humidity above the crop which is extremely difficult especially in a fast-growing crop. Pruitt used a lysimeter at Davis. He calculated  $e_s$  from the temperature of the leaf surface obtained with thermocouples, assuming the relative humidity in the stomata to be 100%. Wind and vapor pressure were measured 1 m above the crop. Pruitt concluded that the method is more promising, even with less accurate instruments, than the other methods.

Other equations which will be given here as examples are taken from the paper by Rohwer (33). In most cases, states the author, the results obtained



on the basis of these equations were disappointing. Fitzgerald carried out excellent observations on evaporation under controlled laboratory conditions as well as natural conditions, and arrived at the following equation:

$$\text{Evaporation, } E, \text{ in./24 h} = (0.40 + 0.199w)(e_s - e_d)$$

where  $w$  = average wind speed on the soil or water surface, in miles/h

$e_s$  = average vapor pressure at saturation at the temperature of the water surface, in. Hg

$e_d$  = average vapor pressure of saturated air at the dewpoint, inches Hg

Carpenter established other constants for Fitzgerald's equation. On the basis of observations with a Piche evaporimeter, Russell obtained the following equation:

$$E = \frac{(1.96e_w + 43.88)(e_w - e_d)}{B}$$

where  $e_w$  = vapor pressure

$B$  = barometric pressure, inches Hg, measured at  $32^{\circ}\text{F}$

This equation takes into account the barometric pressure, but not the wind speed.

Stelling based his equation on metric units, and so  $E$  and  $(e_s - e_d)$  are given in millimeters, and  $w$  is in m/sec. His equation is:

$$E = (0.8424 + 0.01056 w)(e_s - e_d)$$

The equation developed by Rower himself includes more climatological factors and takes the following form (the symbols represent the same parameters as above):

$$E = (1.465 - 0.0186B)(0.44 + 0.118w)(e_s - e_d)$$

Rower found that the vapor transfer coefficient is a function of the barometric pressure or height, and that there is an average ratio of 0.771



between evaporation from a lake and that from a pan.

The equations presented in this brief review were developed some time ago. However, there are a number of relatively recent studies giving similar equations proposed by scientists in Russia, Argentine (1), and in other parts of the world (18). In all cases, the equations based on the vapor pressure deficit according to the principle of Dalton deal with the definition of the amount of water lost by evaporation from a free water surface, and not with evaluating the evapotranspiration rate.

b. Theoretical methods based on the energy balance. Aristotle first stated that three conditions must exist for evapotranspiration to take place: a) the presence of water which is the raw material for evaporation, b) a source of energy to provide the latent heat necessary for evaporation, and c) a gradient in vapor pressure between the evaporating surface and the air (36). The second condition is the basis of the approach to be discussed in this section.

The energy balance method.

In the energy balance method evaporation is obtained from measurements or calculations of the amount of energy available for the evaporation process on the soil surface. Most of the energy supplied to plants is in the form of radiation. Therefore, the radiation balance on the surface, that is, the balance of the different radiation flows between the sun, the sky and the earth, must be first examined. To calculate the energy balance one must have information on the net radiation flow,  $Q$ , in the range of the wave length important to plant growth ( $0.3\mu - 60\mu$ ) through the optical plane parallel to the plant surface.

$$Q = T - R + A - E$$

where  $T$  = total short-wave radiation from the sun and the sky

$R$  = short-wave radiation reflected by the soil and the plant

$A$  = long-wave radiation from the sky and clouds

$E$  = long-wave radiation from the soil and the plant



The energy balance on the plant surface, generally calculated on the basis of unit area of soil, can be thus written:

$$Q = LE + K + S + G$$

where  $LE$  = the energy used as latent heat of evaporation (expressed as the height of water evaporated per unit surface multiplied by the latent heat of evaporation)

$K$  = energy exchange by convection between the surface and the air

$S$  = energy exchange by condensation between the surface and the soil

$G$  = the equivalent energy of the accumulated dry matter, that is, the net photosynthesis multiplied by the heat required to produce the dry matter.

The equation can be simplified by using the fact that as the period is longer, the importance of  $S$  and  $G$  decreases. On an annual basis,  $G \approx Q(0.01)S = 0$ . Thus, these two values are insignificant compared to the other two. The amount of energy absorbed by the plant from the sun, clouds, and sky, can be measured. The different paths into which this energy is divided can also be measured. The amount of energy used as latent heat of evaporation and in heat exchange with the air are the only unknowns in the balance. The ratio between these two unknowns is known as Bowen's Ratio, and can be calculated from the temperature and the humidity gradient between the plant and the air.

$$\text{Bowen's Ratio} - \beta = \frac{K}{LE}$$

Therefore, the energy for evaporation can be expressed as follows:

$$LE = \frac{Q - S}{1 + \beta}$$

Bowen stated that the ratio has no permanent value and changes with wind speed, height of the measurement, and roughness of the surface measured.

In most normal cases,  $\beta$  can be computed from the following equation (27):

$$\beta = 0.606 \frac{(T_w - T_a)}{(e_w - e_a)} \times P/1013$$



where 1013 = standard atmospheric pressure in millibars

P = atmospheric pressure

$e_w - e_a$  = vapor pressure gradient between the evaporating water surface  
and the air

$T_w - T_a$  = temperature gradient between the evaporating water surface  
and the air

0.6 = density ratio of water vapor to the air according to the ratio  
between their molecular weights

From all the above-mentioned, it seems that the successful use of the energy balance as a method for calculating evapotranspiration depends on the following factors:

1. the gradients of vapor pressure and temperature above the evaporating surface
2. the form of air flow -- turbulent or diffusive
3. the gradient of air speed above the evaporating surface.

An example of this type of calculation was reported by Stanhill (36) for Israel's Northern Negev. He used average values of 49 weekly periods of measurement. (All the energy terms are expressed in equivalents of evaporation).

Energy Source	Amount in Equivalents of Evaporation	Fraction
Solar radiation from the sun and sky	8.64	1.00
Solar radiation reflected by the crop	2.00	0.23
Net long-wave radiation from the crop	2.89	0.34
Stored energy in the crop and soil	0.22	0.02
Energy to use dry matter	0.06	0.01
Net radiation available to the crop	3.47	0.40
Evapotranspiration measured with lysimeters	5.12	
Energy transferred from the air to the crop	1.65	



There is a divergence of opinion regarding the degree of practical efficiency of the theoretical evaluations based on the energy balance for estimating evaporation and evapotranspiration. Tanner (41) claims that the calculation of evapotranspiration according to the theoretical approach gives dependable results on an hourly or even a half-hourly basis, in opposition to the other methods of calculation which do not allow measurements of consumptive use for short intervals of less than 5 days.

Usually, the amounts of water used in evaporation and evapotranspiration processes are expressed in mm of water per unit time per unit area. In calculating the energy balance, one obtains practical units of energy flux density which are equivalent to the evaporation units.

$$(R_n L^{-1} \rho_w^{-1})$$

where  $R_n$  = net radiation flux density, cal.  $\text{cm}^{-2} \cdot \text{min}^{-1}$

$$R_n = (R_s \downarrow + R_L \downarrow) - (R_s \uparrow + R_L \uparrow)$$

The arrows indicate the direction of radiation.

$R_s$  = solar radiation in the same units

( $\lambda$  wave length  $\approx 0.3 - 2.0 \mu\text{m}$ )

$R_L$  = long-wave radiation (heat) in the same units

( $\lambda > 2.0 \mu\text{m}$ )

$L$  = latent heat of evaporation at the temperature of the crop

(585 cal-g,  $20^\circ\text{C}$ )

$\rho_w$  = density of water, g.  $\text{cm}^{-3}$

The full energy balance of the crop volume is given by the equation:

$$\begin{aligned}
 R_n + \int_0^z C_p \nabla_H \cdot (\rho u T) dz + \int_0^z \frac{L \epsilon}{R} \nabla_H \left( \frac{ue}{T} \right) dz = S + A + E + \int_0^z C_p \frac{\partial T}{\partial t} dz + \int_0^z C_p \rho \frac{\partial}{\partial t} \left( \frac{\partial T}{\partial z} \right) dz \\
 + \int_0^z \frac{L \epsilon}{RT} \frac{\partial e}{\partial t} dz
 \end{aligned}$$



Where  $A$  = detectable heat flux (for heating the air), in  $\text{cal.cm}^{-2}.\text{min}^{-1}$   
 $S$  = the heat absorbed by the soil, in  $\text{cal.cm}^{-2}.\text{min}^{-1}$   
 $E$  = flow of latent heat (evapotranspiration) in  $\text{cal.cm}^{-2}.\text{min}^{-1}$   
 $T$  = air temperature, in  $^{\circ}\text{C}$  or in  $^{\circ}\text{A}$  according to the Kelvin scale  
 $L$  = latent heat of evaporation on the surface  
 $C_p$  = heat capacity of the humid air at constant pressure,  
          in  $\text{cal.g}^{-1}.\text{degree}^{-1}$   
 $C$  = heat capacity of the crop, in  $\text{cal.g}^{-1}.\text{degree}^{-1}$   
 $M$  = molecular weight of the air, in g  
 $P$  = air pressure, in millibars  
 $R_1$  = universal gas constant  
 $R$  = specific gas constant  $[R_1/M = 2.876 \times 10^3]$   
          in  $\text{mb.cm}^{3}.\text{g}^{-1}.\text{degree}^{-1}$   
= Bowen ratio =  $A/E$  (according to the previous symbols),  
          dimensionless  
 $\nabla_H = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} \text{ cm}^{-1}$   
 $\epsilon$  = the ratio of water:air molecular weights  
 $\rho$  = air density,  $\text{g.cm}^{-3}$   
 $\rho_c$  = average density of the crop volume  
 $\rho_w$  = water density  
 $\gamma$  = psychrometer constant,  
 $a$  =  $K \cdot \ln(Z_2/Z_1)$  dimensionless  
 $e$  = vapor pressure  
 $K$  = Karman Number, dimensionless  
 $t$  = time of measurement, min  
 $u$  = horizontal wind speed  
 $z$  = height above zero point, cm

In order to better elucidate the equation, Tanner (41) makes use of the following illustration:



A more complex mathematical expression is obtained when one attempts to describe the full energy balance of the crop volume. The three mathematical factors at the end of the equation express the changes in the storage of heat by the crop, in the air of the crop volume, and in the latent heat of the crop volume. The energy stored in the process of photosynthesis is only 1-2% and is therefore disregarded.

We shall consider the first expression:

$$\int_{0}^z C_p \rho_c \frac{\partial T}{\partial t} dz$$

It represents the changes in heat storage according to crop height. The expression

$$\int_{0}^z C_p \rho \frac{\partial e}{\partial t} dz$$

represents the change in heat stored in the air of the crop volume, also according to crop height. The expression  $\int_{0}^z \frac{L_E}{RT} \frac{\partial e}{\partial t} dz$  represents the changes in the latent heat stored in the crop volume. These three expressions are only small fractions of the sensible heat flux in the air, A, and of the latent heat used in evaporation, E, on a clear day. However, they can reach 10% of E and A at night when  $\frac{\partial T}{\partial t}$  is large and A and E are small. When  $dz$  approaches zero, all the five expressions under the integral sign approach zero, and so  $R_n = S + A + E$ .



The main disadvantage of this method is the complex route by which the results are obtained, but they are quite satisfactory compared to thos from a lysimeter.

#### The Penman Method (26)

This method of calculating evaporation, or its modification for calculating potential evapotranspiration has proved itself in a number of experiments to be the most exact for determining evapotranspiration (34). This in spite of its being built on complex calculations based on the physical principles of the process, and requires highly complicated microclimatological measurements.

The Penman Method combines the energy balance and the aerodynamic method based on the trasfer of vapor as expressed in the basic equation of Dalton (9),  $E = f_u(e_s - e_d)$  and of Tanner (41) for the energy balance,  $R_n = E + K + S$ ,

where  $f_u$  = function of intensity of horizontal wind

$e_s$  = vapor pressure on the surface of the evaporating water which is the saturation vapor pressure at the temperature of the water

surface,  $T_s$

$e_d$  = vapor pressure of the atmosphere above the evaporating water surface

$R_n$  = net radiation, the difference between the incoming radiation, and the reflected radiation and long-wave radiation

$E$  = the energy for evaporation

$K$  = the energy for heating the air

$S$  = heat storage in the soil, plant tissue, and other materials



The central idea in combining the above two approaches stems from the fact that in order to maintain continuous evaporation two conditions must be satisfied: 1. a supply of the energy required for the latent heat of evaporation, and 2. the creation of a mechanism to transfer the vapor.

The transfer of heat and vapor is controlled by the same mechanism, and other than the difference in molecular constants, the former is regulated by the difference  $T_S - T_A$ , while the latter by the difference  $e_s - e_d$ , where  $T_A$  is the air temperature and  $T_S$  is the temperature on the surface of the evaporating water.

Thus, it is possible to write the Bowen ratio  $K/E$  with a very good approximation as follows:

$$K/E = \beta = \frac{\gamma'(T_S - T_A)}{(e_s - e_d)} \quad .1$$

where  $\gamma'$  = psychrometer constant (0.27 when  $T$  is in degrees Farenheit, and  $e$  is in mm Hg). It has been pointed out previously that net radiation,  $H = E + K + S + C$  (symbols according to Penman),

where  $C$  = heating of the environment of the testing material

$S$  = heating of the material being tested

However, for a period of a few days, and sometimes even for one day, the changes in stored heat,  $S$ , can be disregarded in comparison with the other changes. The same is true regarding  $C$ , and thus,

$$H = E + K \quad .3$$

But from the definition of  $\beta$ , Bowen's ratio is

$$K = E \cdot \beta$$

and so from [1] and [3] we obtain

$$E = \frac{H}{1 + \beta} \quad \text{or} \quad H = E(1 + \beta) \quad .4$$

Penman (26) states that there are difficulties in measuring net radiation directly, but for periods of about a month or more it is possible to estimate the radiation from the daily hours of sunshine.



In order to arrive at mathematical expressions which can be simply measured, the author used an equation developed by Brunt (1939) which expresses the general correlation between the ratios  $R_c/R_A$  and  $n/N$

where  $n/N$  = ratio of actual sunshine hours to the possible number of sunshine hours

$R_c$  = short-wave radiation from the sun and the sky, usually in equivalents of evaporation, in mm per unit area per day

$R_A$  = radiation from the atmosphere, usually in equivalents of evaporation, in mm per unit area per day

$$R_c/R_A = a + b n/N \Rightarrow R_c = R_A (a + b n/N) \quad .5$$

Various values were found for the constants  $a$  and  $b$ . In his experiments at Rothemsted, Penman arrived at the following equation:

$$R_c = R_A (0.18 + 0.55 n/N) \quad .6$$

The result he received was used as a modification in Brunt's equation for determining the heat budget, taking into consideration the entry of short-wave radiation from the sun and the exchange of long-waves between the earth and the sky.

$$H = R_c (1 - r - \mu) - \sigma T_a^4 (0.56 - 0.092 \sqrt{e_d}) (1 - 0.09m) \quad .7$$

where  $r$  = constant of returning radiation from the soil (changes with the season and soil type)

$\sigma$  = Boltzman constant,  $2.01 \cdot 10^{-9}$ ,

expressed in mm evaporation per  ${}^{\circ}\text{K}$  to the 4th power

$T$  = absolute temperature in  ${}^{\circ}\text{K}$

$\sigma T_a^4$  = theoretical radiation from a black body at  $T_a {}^{\circ}\text{K}$

$\mu$  = fraction of  $R_c$  transferred for use in the photosynthetic process.

(The value of  $\mu$  is infinitesimal, 0.005, and therefore disregarded).

$m/10$  = the part of the sky hidden by clouds



Penman's modification of this equation is

$$H = (1 + \beta) E; E = (1 - r) R_A \cdot (0.18 + 0.55 n/N) - \gamma T_a^4 (0.56 - 0.092 \sqrt{e_d}) \cdot (0.1 + 0.9n/N)$$

The expression  $R_A(0.18 + 0.55n/N)$  is used to replace  $R_c$  in the original equation. Each parameter to the right of the minus sign is easy to define and determine. In order to complete the combination of the aerodynamic method with the energy budget, a transfer is made to Dalton's (8) basic equation:

$$E = f(u) (e_s - e_d)$$

If  $E_a$  is taken as the value of evaporation obtained by substituting  $e_s$  for  $e_a$  when  $e_a$  is the vapor pressure, at ambient air temperature (Note: when the temperature gradient between the evaporating surface and the air is zero,  $e_a = e_s$ ), then

$$E = (e_a - e_d) = e_a - \frac{e_d \cdot e_a}{e_a} = e_a (1 - h)$$

$h$ , relative humidity =  $e_d/e_a$

$$\frac{E}{E_a} = f(u) (e_a - e_d)$$

By combining terms, the following form is obtained:

$$\frac{E_a}{E} = 1 - \frac{e_s - e_a}{e_s - e_d} = 1 - \phi$$

$\phi$  is defined at  $e_s - e_a/e_s - e_d$

However, in 1. and 4. it was established that

$$E = H/(1 + \mu) = H / \left[ (1 + \gamma' (T_s - T_a)/(e_s - e_d)) \right]$$

And if  $T_s - T_a = \frac{e_s - e_d}{\Delta}$  where  $\Delta$  is the slope of  $e$  vs.  $T$ , then



$$H/E = \frac{1 - \gamma(e_s - e_d)}{\Delta(e_s - e_d)} = 1 + \gamma \cdot \phi / D \quad [12]$$

and therefore,

$$E = \frac{(H \cdot \Delta + E_a \cdot \gamma)}{\Delta + \gamma} \quad [13]$$

From the above it is seen that evaporation can be estimated only from the conditions of the air, and if necessary, estimate of the evaporating surface's temperature can be obtained and used to indicate external evaporating conditions. In addition to the necessary constants which can be obtained from standard sources, other climatic parameters are needed, such as average air temperature, average dew point, and period of sunshine.

On the basis of Equation [13], Penman (28) estimated values of  $E_0$  for a number of months at Lake Hefner:

Month	Observation	First Calculation	Corrected Value
August, 1950	6.8"	7.4"	7.8"
November	6.0	2.4	5.7
February, 1951	0.4	1.9	1.0
May	4.4	6.1	4.0
August-July	54.9	57.5	56.6

Note: The corrected values are in accordance with changes in heat storage.

#### Estimation of Potential Evapotranspiration by the Penman Method

In Penman's (28) opinion, potential evapotranspiration is a term unnecessarily extended describing potential transpiration. From his definition of potential transpiration, that is the amount of water lost by transpiration per unit time by a dense annual crop of uniform height completely covering the ground and never suffering from lack of water, it is clear why he views the



term potential evapotranspiration, which includes a combination of transpiration and evaporation, to be unnecessarily extended.

In estimating potential evapotranspiration, Penman (28) used two approaches, one empirical and the other analytical.

The empirical approach was based on the assumption that in any location it is possible to estimate evaporation on the basis of equations which he developed in 1948 (26), and by finding the conversion factor,  $f$ , which gives the potential evapotranspiration rate.

$$E_t = f \cdot E_o$$

The empirical approach attempts to find empirical  $f$  values, and as mentioned previously in this review, Penman found that these values change with the season:

<u>Season</u>	<u><math>f</math></u>
May-August	0.8
November-February	0.6
Annual average	0.75

The analytic approach attempts to find theoretical values for the factor  $f$ . In the first stage of Penman's work with Schofield (27) in 1951, a theoretical expression was found for  $f$  composed of three factors: vapor pressure factor ( $f_e$ ), stomatal factor ( $f_s$ ), and the day length factor ( $f_{dl}$ )

$$F = f_e \cdot f_s \cdot f_{dl}$$

The method is based on the measurement of resistance to diffusion of water vapor from the leaf to the outside atmosphere as a function of stomatal geometry. The deficiency of this approach of Penman is that one must still find  $E_o$  in order to obtain  $E_t$ . This difficulty was later overcome in 1952 by combining the aerodynamic and energy approaches for the loss of water by surfaces due to transpiration.



On the assumption that the plant cover surface temperature determining sensible heat transfer to the air is equal to the temperature within the leaf (which determines the leaf's vapor pressure), the following two formal equations are obtained:

$$1. \quad E_t = f_{(u)} (e_t - e_d(SD))$$

(see note below regarding SD)

$$2. \quad H_t = E_t + K_t$$

These are used to arrive at a third equation

$$E_t = (\frac{\Delta}{K} H_t + E_a) / (\frac{R}{K} - \frac{1}{SD})$$

where  $E_t$  = transpiration rate.  $E_t$  will always be less than  $E_o$  since  $S < 1$  and  $H_t < H_o$

$H_t$  = heat budget of transpiration

$H_o$  = heat budget of evaporation

$S$  = Stomatal term. Its value is about 0.9, but always less than 1.

In the empirical equation  $S = f$ . In most crops this term is a function of day length, whereby in daylight the stomata are open and evaporating. Thus, the hours of evaporation are limited by day length, and so in order to arrive at a value by means of a number of simplified assumptions, it is possible to find a function for day length, D:

$$D = \frac{N}{24} + \frac{a}{b\sqrt{t}} \sin \frac{N\sqrt{t}}{24}$$

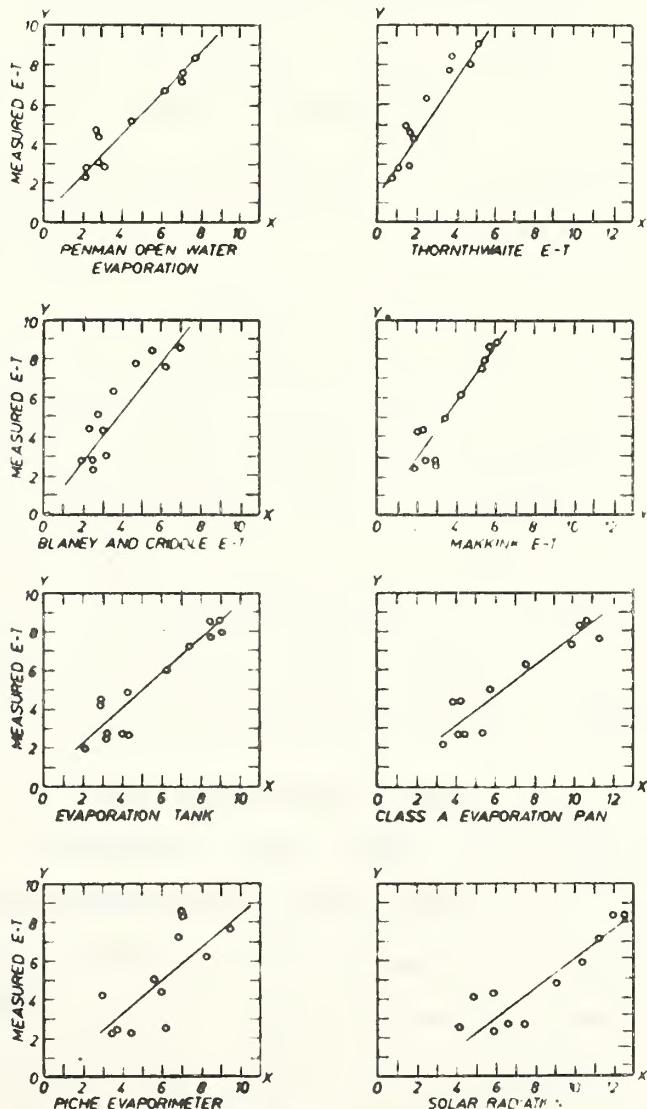
where  $N$  = possible daylight hours

Therefore, D is the major factor in the seasonal variations mentioned in connection with the f values. (This equation is still unsuitable for practical use, but nevertheless provides a basis for an additional generalization concerning potential evapotranspiration). Stanhill (34) reports that he compared a number of methods for calculating potential evapotranspiration by means of climatic



data, and tested certain methods based on physical analysis. Only one was found suitable for practical and routine use in the field. This is the method described by Penman (26). Furthermore, he states that among the 8 methods studied (see following table), the best was Penman's since the regression slope was close to unity. The correlation coefficient was also close to unity, - and the standard error was very small.

The correlation between measured evapotranspiration and related variables (daily mean values for monthly periods).



The correlation between measured evapotranspiration and related variables (daily mean values for monthly periods).



Empirical Methods Based on Temperature, Radiation, and Other Climatic Data

The Christiansen method for estimating evaporation from a pan, and modifications for estimating evapotranspiration. At the University of Utah a number of studies have been conducted (1, 8, 7, 14, 23, 24, 22) under the direction of Christiansen. Their purpose was to develop equations which:

1. include most of the climatic factors influencing evaporation and evapotranspiration
2. are based on standard climatic data published by the meteorological services
3. use data easily obtained and applied for computation.

The approach in these studies was a statistical empirical one. The basic equation is

$$E = K \cdot R \cdot C$$

where  $E$  = evaporation or evapotranspiration

$K$  = a constant determined by analysis of many sources, dimensionless

$R$  = the theoretical solar radiation reaching the outer face of the earth's atmosphere

$C$  = empirical factor obtained from a number of sub-factors, each of which expresses the effect of some climatic factor on the evaporation or evapotranspiration process. Dimensionless.

Patil (23) studied evaporation problems in Northern Utah and relied on the work of Christiansen. His studies were conducted at 5 experimental stations, and the equation developed included factors of temperature, wind, relative humidity, and hours of daily sunshine expressed as a percentage of the total possible number of hours. He concluded that evaporation must be basically a function of the available energy received from the solar radiation. However, since the solar radiation reaching the earth's surface is measured



at a number of different locations, it is preferable to calculate the radiation received at the outer edge of the atmosphere and so the results will have a common denominator.

In order to calculate the equation, a large amount of data was gathered. Part of it was analyzed to determine the ratio between this data and the evaporation measured at the same location. All the data used in the analysis was included as part of the factor C.

$$C_c = C_t C_w C_s C_h C_m C_e \dots \text{etc.}$$

where T, W, S, H, M, E = temperature, wind, hours of sunshine, relative humidity, month, and elevation above sea-level, respectively.

Theoretically, every factor represents the specific effect of the climatic factor (for example,  $C_w$  represents the effect of wind speed on evaporation), whereas all the other factors are constant.

In 1962, Patil (23) began determining the coefficients by use of second order equations, and added many months of observation (a total of 3232).

The transfer to using second order equations came after it became clear that the use of a linear equation for high values of the climatic factors gave coefficients with too high values, as the increase of the coefficient values does not grow linearly with the increase in the climatic factor. Usually for each sub-coefficient there is a general expression in the form of a second order equation.

The equations which Patil established for determining the climatic coefficients are:



$$K = 0.530$$

$$C_T = 1,203 + 0.0463T - 0.000204T^2$$

$$C_W = 0.786 + 0.00385W - 0.0000047W^2 \quad (W = \text{miles/day})$$

$$C_S = 0.458 + 0.00568S - 0.0000136S^2 \quad (S = \%)$$

$$C_H = 1.141 - 0.00336H - 0.0000045H^2 \quad (H = \% \phi)$$

$$C_E = 0.936 + 0.00350E - 0.0000156E^2 \quad (E = \text{units of 100 ft})$$

$$C_M = 1.000 + 0.098\cos(3ON-20) \quad (N = \text{month, with January} = 1)$$

In order to simplify the use of the equation, he entered all the coefficient values and their logarithms in tables.

The latest work published by Christiansen and Mehta (8) in 1965 includes most of the sources contained in the studies by Patil (23), Pate (24), and Mathison (22), with additional new data from Nigeria, Canada, and Peru. His final equation and the coefficients which he used are:

$$E_v = K \cdot R \cdot C_T C_W C_H C_S C_E C_M$$

where  $K = 0.468$

$R$  = radiation from outside of the earth, in units of evaporation.

Values of  $R$  can be obtained from a table prepared by Napier and Shaw (1942). See Appendix 1.

$$C_T = 0.1532 + 0.000874T + 0.0000546T^2$$

Average monthly temperature in  $^{\circ}\text{T}$ , when  $^{\circ}\text{F} = 20^{\circ}\text{C}$ ,

$T = 68^{\circ}$ , then  $C_T = 1.8$ .

$$C_W = 0.79 + 0.0037W - 0.00000383W^2$$

Average wind speed measured at the height of the pan in miles per day.

$C_W = 1.0$  when  $W = 60$  miles/day or 96.56 km/day



$$C_H = 1.202 - 0.00353H - 0.0000381H^2$$

H = Average relative humidity during the day or the average noon-time relative humidity.

$C_H = 1.0$  when  $H = 40\%$ .

$$C_S = 0.402 + 0.019S - 0.0028S^2 + 0.0000017S^3$$

S = Daily hours of sunshine expressed as a percentage of the maximum possible number of hours.  $C_S = 1.6$  when  $S = 80\%$

$$C_E = 0.9654 + 0.0362E - 0.0016E^2$$

The height in units of 1000 ft

$C_E = 1.0$  when  $E = 1$  (1000 ft)

For  $C_M$  no equation was proposed, but the values have been included in a table according to 16 climatic regions.

In the event that some of the climatic data is lacking, the equation still remains applicative since all the coefficients for the approximate average value of the climatic factor are equal to 1.0. In the case of application, the numerical value of the missing climatic factor can be estimated or deleted as though the coefficient was taken equal to 1.0.

The method of calculating the different coefficients and constants in Christiansen's equation. The first step taken by Christiansen in his work was to use data at hand to compute  $C_T$  -- the temperature coefficient, with all the other climatic factors constant. Since the basic equation is

$$E_V = K \cdot R \cdot C, \text{ then } f(T) = E_V/R$$

In the first analysis, the most appropriate linear function was the equation

$$E_V/R = 0.00744T - 0.0439 = K_t \cdot C_T$$

for  $T = 68^{\circ}\text{F}$ ,  $C_T = 1$ , and so  $K_t = 0.462$   
and upon dividing by  $K_t$ ,

$$C_T = 0.0161T - 0.095$$



The second step was to find the ratio

$$f_w = E_V / R \cdot K_t \cdot C_T$$

The appropriate linear function found was  $K_W \cdot C_W$ .

The coefficients and constants of all the climatic factors were similarly found.

The constants obtained by each of the steps were multiplied so that the final value of  $K$  was

$$K = K_t K_W K_S K_H$$

Experiments using Christiansen equations to estimate evapotranspiration.

The first experiment was made by Grassi (14) in 1964 from data obtained from the work by Jensen and Haise. He entered the information in tables and computed  $R$ -values for the different periods from which the data was obtained.

The method he used for determining the coefficients was based on Christiansen's mathematical analysis, but an attempt was made to reduce their mutual dependence.

To calculate evapotranspiration, Grassi included a number of additional coefficients:

$C_{cl}$  = coefficient of cloud cover, expressed on a scale from 0 - 10

$C_{tx}$  = coefficient of average maximum temperature during the given period

$C_{td}$  = coefficient of the average difference between maximum and minimum temperatures during one year

and also coefficients which characterize the specific crop:

$C_{rc}$  = coefficient of crop cover, expressed as a percentage of full cropcover

$D_a$  = the length of time in days after full crop cover

$V_c$  = vegetative cycle expressed as a percentage of the total number of days from seeding to harvest.



Grassi's first equation was in accordance to the general scheme:

$E_t = k \cdot CR \cdot C_{cl} \cdot C_T \cdot C_{td}$  where each time a different plant factor is added to the climatic factors according to the crop.

The first series of equations included three equations -- for alfalfa, annual crops, and orchards (1a, 1b, 1c).  $C_{rc}$  is the factor included in the calculation of evapotranspiration for an alfalfa field:

$$E_t = K \cdot C_R \cdot C_{cl} \cdot C_T \cdot C_{td} \cdot C_{rc} \cdot F$$

$F$  is the crop factor obtained by determining the ratio between actual and calculated evapotranspiration. Similarly,  $V_c$  was included as the most suitable for annual crops, while for orchards only the correction factor  $F$  was included.

It seems that for the exact estimate of evapotranspiration the relative effect of  $C_{rc}$ , the crop cover, is more important than the effect obtained by introducing  $V_c$ , the total number of days between seeding and harvest.

A second series of equations was developed on the basis of radiation from the sun and the sky,  $R_s$  (2a, 2b, 2c), and includes the same plant factors. The third series is based on the correlation between pan evaporation and evapotranspiration:

$$E_t = K \cdot E_r \cdot C_t \cdot C_{crc} \cdot F$$

The degree of accuracy of the different equations he developed depends on the accuracy of the soil measurements to determine actual evapotranspiration. Furthermore, there is a problem of adapting the equations to other parts of the world as they are based on data from the western United States. But it is possible that the error will not be large in other irrigated arid and semi-arid zones.

In 1965, Al Barrak (1) conducted an experiment in central Iraq to study evaporation in potential and actual evapotranspiration. The data were collected from standard climatic measurements made in Iraq, as well as from a limited



number of actual evapotranspiration data for cotton and winter grain. The data were presented in millimeters for the period between irrigations, and determined by the amount of water applied in irrigation plus rainfall minus the amount of water which passed through the soil in drainage. One of the purposes of this work was to develop a modification of the existing equations, or to find new equations which would be more suitable to the conditions in central Iraq. It was found that the modifications could be achieved by changing one or more climatic factors in the equations, or by changing the constants. The purpose was to arrive at a minimum total of absolute differences between the measured and the calculated results for the various months.

In order to achieve good agreement of the various equations to conditions in central Iraq, he included a coefficient which could represent the fluctuations in the months of the year, as a function of sin or cos. For example:

$$C_M = 1.0 + A \cos (C_m + B)(\pi/6)$$

where A and B = constants

M = number of the month.

A coefficient of this type can also be determined for other factors. If the ratio of measured to calculated evaporation is plotted against the months, then the cos curve is a better fit for the points. (The constants A and B are defined from the new curve obtained).

The modifications of the equations mentioned in this review as made by Al-Barraq are as follows: The Utah equation for determining evaporation,  $E = KCR$ , was modified by changing the coefficient of the months,  $C_M$ , so that the results would more closely agree with the data obtained.

The original values were taken from the work by Christiansen in 1960 according to data in a table. These were first multiplied by the monthly ratio between the calculated and actual evaporation, and the result plotted on a curve against the months of the year. The extent to which the curve fitted the points can be described by the equation:



$$K \cdot C_M = 1.30 \times 1.0 + 0.23 \cos \left[ (M + 3)(\pi/6) \right]$$

And the final modification of the Utah equations became

$$E_V = 0.611R \cdot C_T \cdot C_W \cdot C_H \cdot C_S \cdot C_M$$

$$\text{in which } C_M = 1.0 - 0.23 \cos \left[ (M + 3)(\pi/6) \right]$$

The results obtained from this equation were better than those obtained with the original equations. The total absolute differences between the modification and the monthly measured values was 11.0 compared to 50.9 with the original equation.

He modified the Blaney-Criddle equation (see discussion below on this equation) for determining actual evapotranspiration (in the light of insufficient data) on the basis of assumptions that the K values should be calculated so that the evapotranspiration for January would be 3.0", and for July 10.5", (The numbers represent the mid-points in what he considered to be a logical range of values).

The equation he obtained for K as a function of temperature was:

$$K = 0.43 + 0.0074t$$

and so  $E_t = k \cdot f = (0.43 + 0.00074t) \cdot f$

The Grassi equation (39), based on evaporation, can be treated in a similar manner to obtain

$$E_t = k \cdot E_V \cdot C_t$$

$$K = 0.568$$

$$C_T = 2.115 - 0.0164$$



### The Blaney-Criddle Method for Estimating Evapotranspiration

The Blaney-Criddle Method (2, 3, 4) also adapted to calculate pan evaporation, is based on the correlation between average monthly consumptive water use and temperature, the percentage of monthly hours of sunshine of the total hours for the year (obtained from tables according to the latitude of the location measured), and a plant coefficient based on the plant type and growing season.

The method was developed by measuring the above correlation, and the coefficients obtained can be readily computed if one knows the monthly temperature, the latitude, the growing or irrigation season, and the monthly percentage of sunshine hours. The method is expressed mathematically as follows:

$$U = K \cdot F = \sum kf \quad \text{and} \quad f = \frac{p \cdot t}{100}$$

where  $U$  = consumptive water use of the crop (evapotranspiration for the entire period)

$F$  = total of the factors affecting monthly consumptive water use

$K$  = empirical coefficient, seasonal average

$t$  = average monthly temperature,  $^{\circ}\text{F}$

$p$  = ratio between total hours of daily sunshine per month and the total hours of daytime, expressed as a percentage (given in a table according to latitude)

$k$  = monthly consumptive water use

$f = p \cdot t / 100$  = monthly consumptive use factor. (By dividing by 100, a  $k$  - value of close to 1 was obtained)

$u = k \cdot f$  = monthly consumptive use, in inches

In metric units, the monthly consumptive use (in mm) is

$$u = k \cdot p \frac{(45.7 t + 813)}{100}$$



The empirical coefficient, K, is obtained by summarizing the periodic consumptive water use values, U, for an important crop in a number of locations, and then calculating the periodic consumptive use factor, F. From the above equations it is clear that  $K = U/F$ . Determinations of this type are difficult to make, and can be a source of errors due to the different conditions under which the measurements are made by different workers. Therefore, variations are to be anticipated in the values of the calculated coefficient, K. The authors relied on their personal knowledge of the physical conditions under which the experiment was conducted, and analyzed all the available data in order to prepare coefficient tables suitable for different crops under normal conditions, without taking into account the location where the crop was grown. It has been found (24) that the variation in k (the monthly coefficient) for calculating evaporation ranges from 0.84 to 0.18. The authors claim (3) that when short intervals are concerned, such as a month or less, one must recognize the factors liable to affect the crop together with the climate. For example, a crop may be attacked by insects and lose many leaves, thus reducing the plant's ability to transport water in the transpiration process.

The authors also prepared an appropriate table for the monthly coefficients, k, based on values obtained from field measurements.

The Blaney-Criddle equation is in wide use throughout the world. Engineers use it as a basis for estimating consumptive water use despite the fact that the monthly coefficient, k, is not permanent and changes during the season with temperature, other climatic factors, and characteristics of the crop (2). In Israel this equation is used (the metric form), and it has been found that the coefficients developed by Blaney and Criddle in California are suitable also in Israel. The authors attributed the wide use of the equation (2) to the fact that despite the disregard of many factors affecting evapotranspiration, the most important factors are the temperature and the sunshine. Records of sunshine are not always available to the farmer or engineer, while on the other hand, temperature is available at every point in the world. Thus, the sunshine



effect is determined by calculating the theoretical day length during the vegetative period of the different crops.

The ratio between monthly daylight hours to the yearly daylight hours, expressed in percentages, was entered into tables covering most of the cultivated agricultural areas of the world. The tables have a deficiency in that the data are theoretical and do not sufficiently represent the changing conditions in the given field.

In order to simplify as much as possible the use of this equation, a nomograph was prepared (See Appendix 2 ).

#### The Thornthwaite Method

In 1948, Thornthwaite developed an empirical equation also based on temperature. He assumed that the temperature is a good index of energy, and developed an exponential ratio between the average monthly temperature and the average potential evapotranspiration (38). He assumed that the amount of water lost in transpiration from a completely covered area depends more on the solar energy and temperature than on the type of crop, as long as we supply it with necessary amount of water.

The equation which he developed to estimate unadjusted potential evapotranspiration is

$$e = 1.6(10t/l)^a$$

where  $e$  = potential evapotranspiration

$t$  = average temperature,  $^{\circ}\text{C}$

$l$  = periodical or annual heat index

$a$  = coefficient

The relation between these symbols is given by the following equations:



$$i = \text{monthly heat index} = (t/5)^{1.514}$$

$$I = \sum_{1}^{12} i$$

$$a = 0.00000075I^3 - 0.0000771I^2 + 0.0179211 + 0.49239$$

Thornthwaite based his equations on evaporation data from a number of fields with latitudes ranging from  $29^{\circ}\text{N}$  -  $43^{\circ}\text{N}$ .

In order to correct the results obtained, he altered his evapotranspiration equation to give the adjusted potential evapotranspiration:

$$e = e(N/30)(H/12)$$

where the correction is based on the number of days in the month N, and the average number of daylight hours during the month = H.

Obviously, the equation in this form is not sufficiently applicative, mainly because of the difficulty in calculating a, and in order to transform it into a more useful equation, an attempt was made (50) to develop a graphic technique (see Appendix 3) to determine the potential evapotranspiration according to Thornthwaite's method. Further changes were made in order to arrive at intervals of a week and even one day in estimating potential evapotranspiration, and corrections were also made regarding the soil water status. Prior to this, in 1957, Thornthwaite and Mather (39) prepared useful tables to calculate potential evapotranspiration rate, and in 1959 Van Hylk (44) developed a nomogram for the Thornthwaite method which seems to provide the easiest arrangement for estimating the potential evapotranspiration rate. (See Appendix 4).

A discussion on this subject can be found in the paper by Van Wijk and De Vries (43) who concluded that there is no theoretical possibility for estimating evaporation and for depending solely on temperature data as an indicator of energy available for the different processes. It can be assumed that the temperature is the important factor, if the equation is corrected empirically to the average conditions of a wide region or to the special conditions of a specific area. In both cases, the equation will not be generally applicable. The above



authors base their claims on the large difference existing between the flow of solar radiation and the temperature. For example, at a certain location they measured a temperature of  $5^{\circ}\text{C}$  in November and  $5.4^{\circ}\text{C}$  in March, while the average radiation intensity was  $67 \text{ cal/cm}^2$  in November and  $195 \text{ cal/cm}^2$  in March. Since evapotranspiration is a function of the number of calories, it is clear why Thornthwaite could not do without the heat index,  $I$ , as an empirical expression to complement the temperature lag behind the amounts of radiation. In summary, it is difficult to find any theoretical justification for Thornthwaite's method, even though it is based on temperature as the main factor, and the method has been accepted, apparently, because of the ease in its use rather than due to the accuracy which it provides.

Pelton, King and Tanner (25) claim that average monthly temperature and monthly evapotranspiration also depend on radiation. Because of the seasonal changes in radiation, the temperature and evapotranspiration are highly correlated, and so the estimate of evapotranspiration from a correlated temperature will also be suitable for actual evapotranspiration. The experimental equation of Thornthwaite for monthly estimates includes a correction for the general change in radiation according to latitude, but does not take into account as well the temperature lag after radiation. This lag in certain cases produces a large error in the monthly estimate. The error is smallest during the period May to August, and also in the yearly estimate. However, in the spring and winter, the errors are quite serious. Correction of the results to arrive at the adjusted potential evapotranspiration is possible, primarily due to the constancy of the amounts of radiation for long periods. It appears on the basis of experiments that also for evapotranspiration values the variability is low during the growing season and for the yearly calculation, so that if the estimate is made after adjusting the potential evapotranspiration, the Thornthwaite method is more useful than the estimate of unadjusted potential evapotranspiration.



In their opinion, a method based on radiation is more suitable for estimating potential or actual evapotranspiration. The average temperature method is more useful when the estimate is needed for the growing season or for the entire year, and also in a location where radiation data are unavailable. In the case that the average temperature method is used, a correction must be made for thermal lag.

One should not rely on the average temperature method for short periods such as 3 - 6 days, because the measurement of temperature is not suitable for representing the physical conditions affecting evapotranspiration. Conversely, the measurement of new radiation is suitable for obtaining a good estimate of evapotranspiration, even for brief periods of days or hours.

#### S U M M A R Y

The literature survey included a number of equations developed to estimate evaporation and evapotranspiration using climatic data. A large number of equations exist which have not been mentioned, however those discussed here represent the various approaches and are also the ones most commonly used.

The various methods have been evaluated by different researchers. In a number of cases, not only the degree of accuracy was considered, but also the relative cost of the methods. Stanhill (34) prepared the following table of comparisons:



TABLE 2

A COMPARISON OF THE EQUIPMENT AND TIME NEEDED IN EIGHT  
METHODS OF CALCULATING POTENTIAL EVAPOTRANSPIRATION  
FROM CLIMATIC DATA

Method	Equipment (minimum requirements)	Cost of equipment (Israeli pounds)	Time needed for observ- ations (minutes/ day)	Time needed for each calculation (minutes)
Penman	Thermometer screen and thermometers, sunshine recorder and totalizing anemometer	1,050	10	10
Thorntwaite	Thermometer screen and thermometers	550	5	5
Blaney-Criddle	Thermometer screen and thermometers	550	5	5
Makkink	Thermometer screen and thermometers, sunshine recorder	850	5	5
Evaporation tank	Tank, still well and micrometer depth gauge	450	5	5
Evaporation pan	Pan, still well and micrometer depth gauge, wooden platform	100	5	5
Piche evaporimeter	Thermometer screen and evaporimeter	505	5	5
Solar radiation	Sunshine recorder	320	5	5
Gravimetric soil moisture sampling	Veihmeyer tube, hammer and jack, sampling tins, triple beam balance and drying oven.	650	180	30

The table shows that the methods based on physical analysis (Penman) are the most expensive, while those based on correlation with evaporation from a free water surface (Class A pan) are the cheapest. The empirical methods for estimating evapotranspiration (Blaney-Criddle and Thorntwaite) and the direct sampling methods are intermediate in the cost of equipment required.



From the point of view of accuracy attainable, Stanhill arrived at the following results:

A comparison of eight methods of calculating potential evapotranspiration from climatic data

TABLE 1

A COMPARISON OF EIGHT METHODS OF CALCULATING POTENTIAL EVAPOTRANSPIRATION FROM CLIMATIC DATA

Method	Monthly periods			cv (y/x)**	Monthly periods			cv (y/x)**
	Regression*	r			Regression*	r		
Physical Formulae	$y = 0.97x + 0.96$	0.96	12		$y = 0.96x + 1.12$	0.76		36
Penman								
Empirical formulae								
Thornthwaite	$y = 1.48x + 1.85$	0.94	16		$y = 1.35x + 1.76$	0.73		38
Blaney and Criddle	$y = 1.22x + 0.72$	0.90	20		$y = 1.15x + 1.02$	0.70		40
Makkink	$y = 1.49x + 0.06$	0.95	15		$y = 1.45x + 0.15$	0.75		37
Instrument methods								
Evaporation tank	$y = 0.86x + 0.74$	0.94	16		$y = 0.84x + 0.73$	0.76		37
Evaporation pan	$y = 0.70x + 0.47$	0.95	15		$y = 0.72x + 0.36$	0.77		36
Piche evaporimeter	$y = 0.88x + 0.03$	0.69	30		$y = 0.94x + 0.35$	0.63		44
Solar radiation	$y = 0.72x + 1.04$	0.91	20		$y = 0.70x + 0.87$	0.77		20
			3***					10***
Soil sample method								
Gravimetric determinations			3***					10***

\*     x measured value of potential evapotranspiration, mm per day;  
 y calculated values of potential evapotranspiration, mm per day.

\*\*    Coefficient of variation around regression line, percent of mean y-value.

\*\*\* Standard error, percent of mean y-value



The best method, according to the above tables, was Penman's. Of the empirical equations tested, Thornthwaite's was more accurate than Blaney-Criddle, which in turn was less accurate than the results obtained by the correlation between evaporation from a free water surface in a pan and the evapotranspiration.

Christiansen (7) attributes the inaccuracies obtained with the Blaney-Criddle equation in the Middle East region to the fact that the values of K, the yearly coefficient, are based on determinations made in the western United States in areas where the values obtained are too low for hot, dry countries.

In another paper (24) Christiansen states that it is difficult to compare the actual evaporation to the values calculated from the Blaney-Criddle equation for pan evaporation because of the large change of the monthly coefficient, k, with location and season. Another reason is the dependence of the correlation values on the user of the equation. The fluctuations in the K values represent the main problem in using this equation.

Concerning the theoretical equations based on vapor pressure deficit, the main problem is related to the fact that the calculations use the temperature of the free water surface. The temperature of the water's surface is not available, and thus it is necessary to use the average temperature when computing evaporation. A comparison (1) showed that the temperature of the free water surface in a pan is slightly higher than the air temperature, so that the result calculated by means of the Rower equation and the others mentioned for the same group, will give evaporation values lower than those which would have been obtained had the water surface temperature been measured. The results obtained by Al Barrak (1) from the Rower equation were as follows: Annual values similar to those measured with an evaporation pan, where the ratio between calculated to actual annual evaporation ranged from 0.94 to 0.99. In all cases, the calculated results obtained were higher



than the actual results measured in the summer, and lower than those in the winter months.

Penman equation: Very high values in the summer. For the months of October-January, the average value of calculated evaporation was slightly lower than the measured evaporation.

Grassi equation (3a): This method based on measurements of a Class A pan gave high values for all the months (on a monthly basis).

Blaney-Criddle equation: Gave correct results for January, but the values were lower than those obtained by the other equations tested for the summer months (June-July) when the ratio between calculated and actual evaporation was 0.53.



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A P P E N D I X



Table 3. Solar radiation, R, at top of atmosphere. Expressed as equivalent evaporation at 20° C.\*

Latitude	Jan.	Feb.**	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	<u>Inches</u>											
<u>North</u>												
60	1.76	3.93	8.53	13.28	18.05	19.51	19.12	15.39	10.23	5.68	2.27	1.19
50	4.59	6.65	11.27	15.12	19.01	19.80	19.72	16.91	12.48	8.70	5.15	3.80
45	6.05	7.99	12.53	15.89	19.34	19.88	19.90	17.52	13.51	10.12	6.60	5.21
40	7.53	9.29	13.69	16.56	19.57	19.89	20.00	18.02	14.45	10.44	8.03	6.67
35	9.03	10.54	14.74	17.12	19.69	19.80	20.00	18.41	15.29	12.66	9.45	8.16
30	10.52	11.72	15.68	17.57	19.70	19.60	19.90	18.68	16.02	13.78	10.80	9.66
25	11.97	12.82	16.50	17.90	19.59	19.28	19.68	18.82	16.63	14.80	12.10	11.15
20	13.35	13.83	17.20	18.10	19.35	18.84	19.34	18.83	17.11	15.74	13.34	12.61
15	14.63	14.74	17.77	18.16	18.98	18.29	18.87	18.70	17.45	16.60	14.50	14.03
10	15.81	15.54	18.20	18.07	18.48	17.63	18.27	18.44	17.65	17.36	15.57	15.36
5	16.88	16.22	18.49	17.85	17.86	16.86	17.55	18.05	17.72	17.98	16.53	16.59
Equator	17.84	16.78	18.63	17.50	17.12	15.99	16.71	17.53	17.67	18.42	17.37	17.70
<u>South</u>												
5	18.68	17.23	18.62	17.03	16.27	15.02	15.77	16.88	17.46	18.68	18.09	18.67
10	19.40	17.58	18.47	16.43	15.32	13.95	14.73	16.10	17.15	18.80	18.70	19.51
15	20.02	17.72	18.19	15.71	14.27	12.79	13.60	15.20	16.70	18.80	19.19	20.23
20	20.52	17.84	17.79	14.87	13.12	11.57	12.39	14.20	16.12	18.70	19.55	20.73
25	20.90	17.84	17.27	13.92	11.89	10.29	11.11	13.17	15.42	18.50	19.77	21.21
30	21.14	17.70	16.63	12.86	10.58	8.95	9.77	12.00	14.61	18.18	19.85	21.56
35	21.28	17.42	15.84	11.70	9.21	7.57	8.38	10.77	13.70	17.72	19.81	21.78
40	21.22	17.00	14.92	10.56	7.80	6.19	6.96	9.49	12.69	17.11	19.66	21.86
50	20.88	15.76	12.68	8.00	5.09	3.59	4.16	6.28	10.31	15.44	19.07	21.65

\* Computed from data by Napier Shaw (1942).

\*\* February computed for average of 28.25 days.



APPENDIX 2

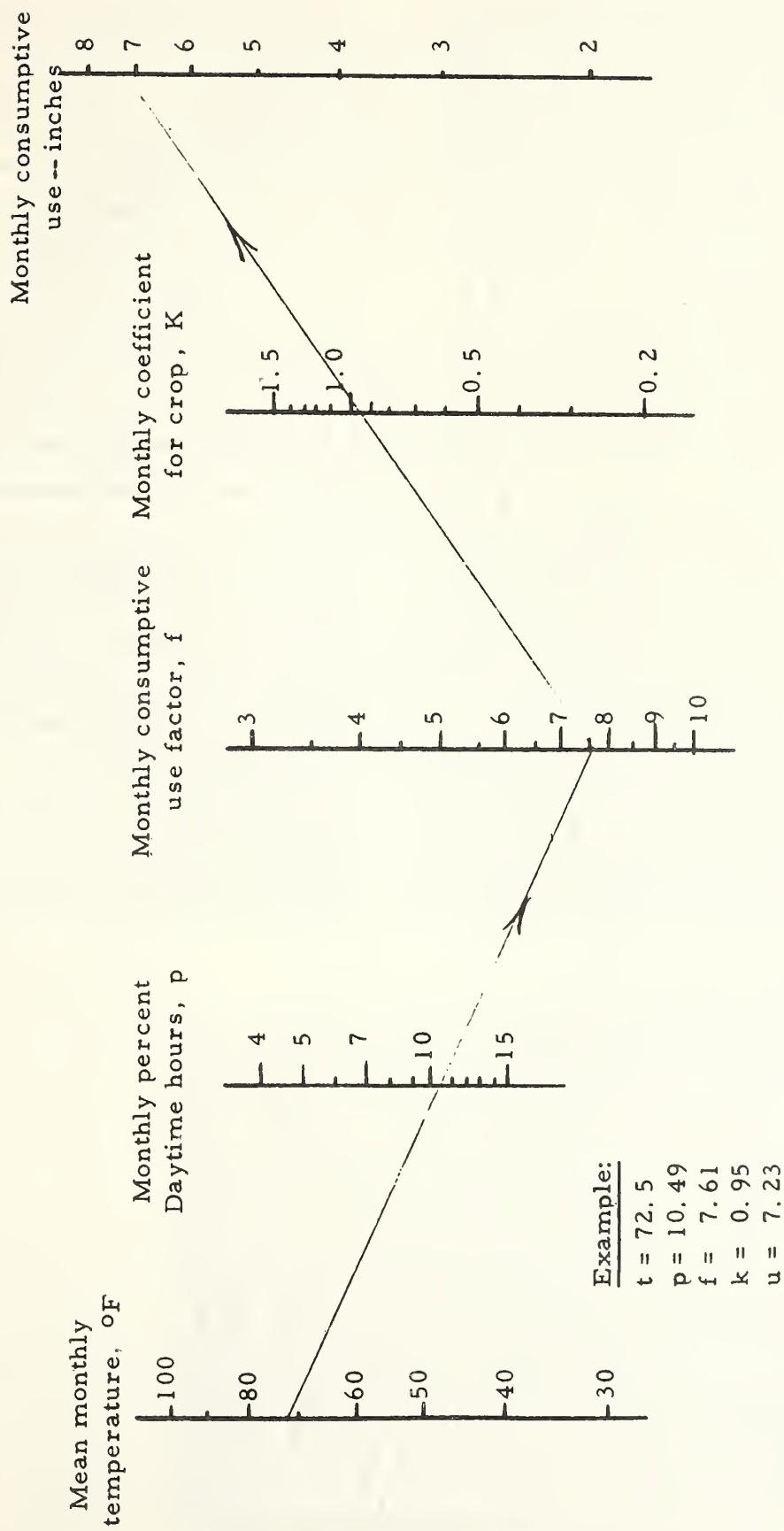


Figure 1 Blaney-Criddle nomograph for monthly consumptive use (Criddle, 1961)



### APPENDIX 3

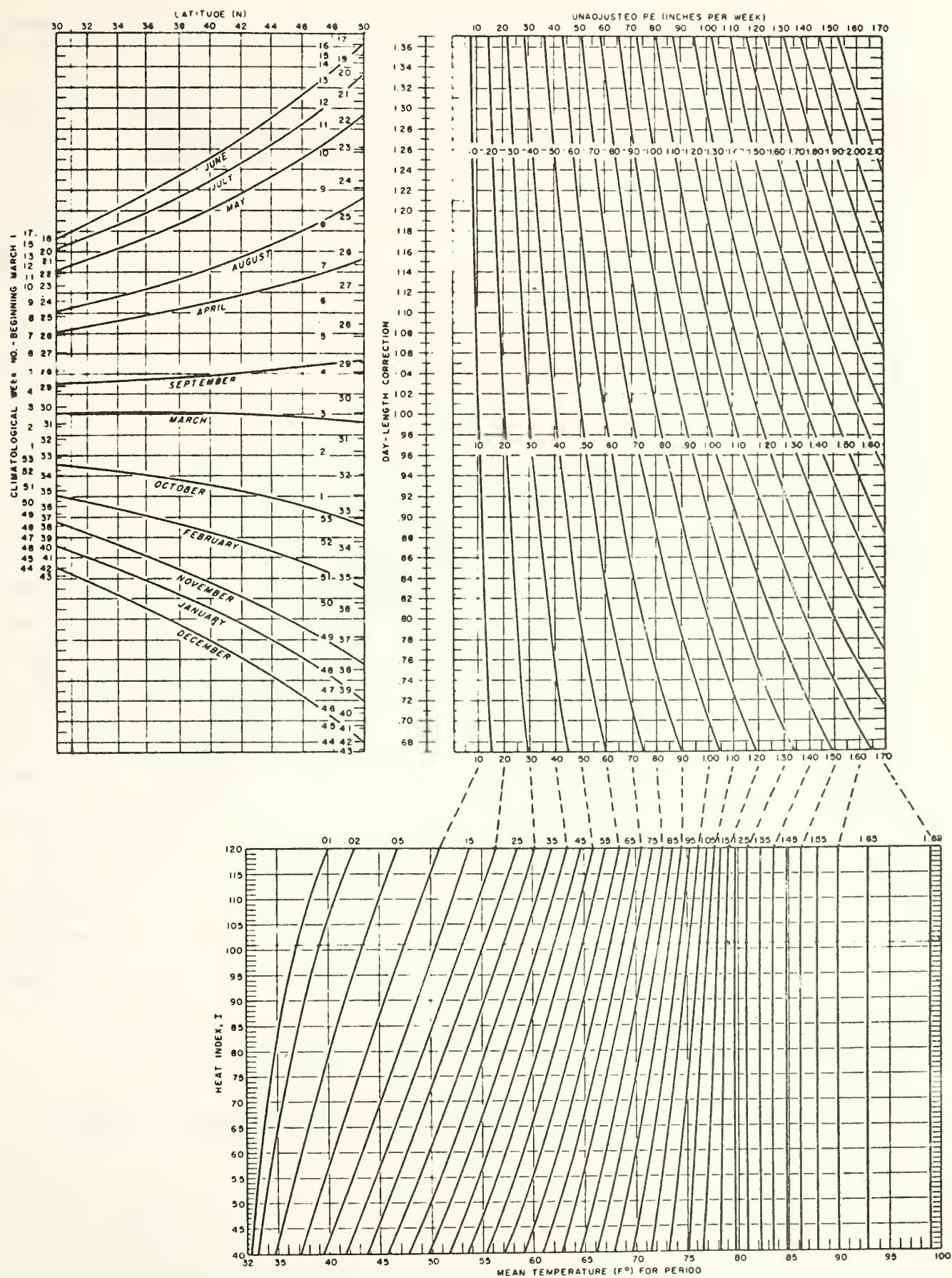


FIGURE 2 —Nomogram for computation of potential evapotranspiration (PE).



## APPENDIX 4

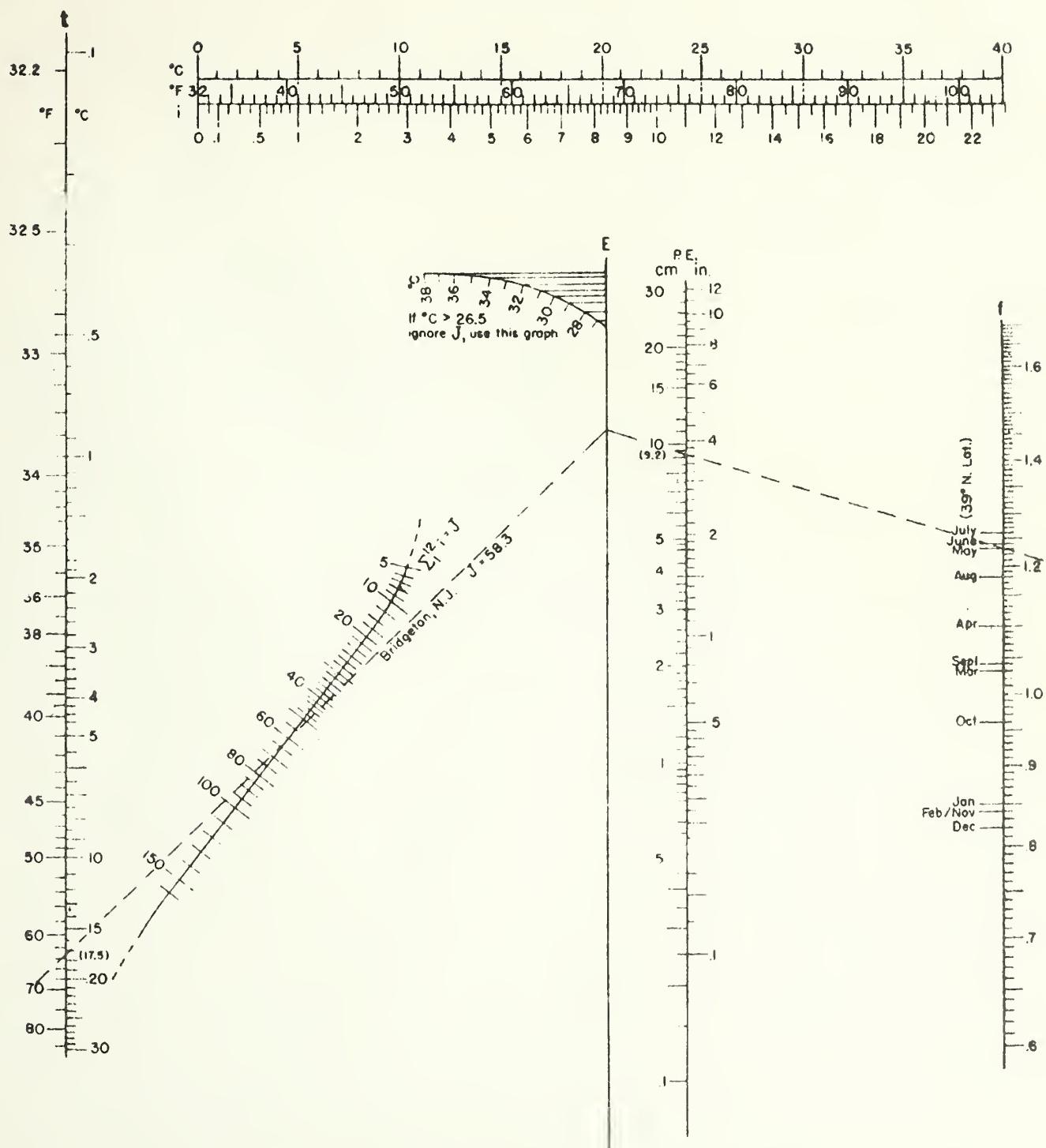


FIGURE 3. A nomogram to determine the potential evapotranspiration according to Thornthwaite's formula.



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